ACRP

REPORT 60

AIRPORT COOPERATIVE RESEARCH PROGRAM

Sponsored by the Federal Aviation Administration

Guidelines for Integrating Alternative Jet Fuel into the Airport Setting

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Guidelines for Integrating Alternative Jet Fuel into the Airport Setting

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), and the Air Transport Association (ATA) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

ACRP REPORT 60

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NOTICE

The project that is the subject of this report was a part of the Airport Cooperative Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

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FOREWORD

By Theresia H. Schatz
Staff Officer
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ACRP Report 60: Guidelines for Integrating Alternative Jet Fuel into the Airport Setting is a handbook for airport operators and others associated with "drop-in" alternative jet fuel production and delivery that summarizes issues and opportunities associated with locating (on- or off-airport) an alternative jet fuel production facility, and its fuel storage and distribution requirements. The handbook identifies the types and characteristics of alternative fuels; summarizes potential benefits; addresses legal, financial, environmental, and logistical considerations and opportunities; and aids in evaluating the feasibility of alternative jet fuel production facilities.

Virtually all of the fuel currently used in aviation operations is derived from petroleum. Petroleum fuel supply and associated pricing (both level and volatility) are key business challenges for the industry. In addition, concerns about environmental impacts compound challenges facing the aviation sector as it continues to meet demand. Drop-in alternatives to jet fuel provide great promise for the aviation industry from environmental, energy security, and economic perspectives. Several demonstration flights recently have shown that technology is available to produce alternative jet fuel that can be used to safely fly existing aircraft. Key challenges to moving forward with commercial use of alternative jet fuel include the formation of an effective business plan addressing production at marketable prices and quantities, with fuel deliverable at the appropriate point in the supply chain. One concept that has received significant industry interest is to locate an alternative fuel production facility on, adjacent to, or with access to an airport to take advantage of known demand. Access to known demand at an airport could encourage investment by an alternative fuel producer in aviation fuel. In order to provide a path forward for locating an alternative fuel production facility and associated infrastructure, research has been provided to evaluate the legal, financial, environmental, and logistical considerations and opportunities associated with launching such a project.

This handbook was developed from the research conducted for ACRP Project 02-18 and will assist airport operators and those stakeholders interested in locating (on- or off-airport) an alternative jet fuel production facility and determining its storage and distribution requirements.

A section is included on frequently asked questions, along with supporting material and worksheets that incorporate regulatory, environmental, logistical, and financial requirements. There are also appendices that provide a primer on alternative fuels, the feedstocks and production technologies for producing alternative fuels, economic benefits, and financial and regulatory considerations.

CONTENTS

Purpose of the Handbook

Production of jet fuel from alternative sources is a growing industry. It is supported by both large, established corporations, such as the international oil companies, and many smaller, new entrants that are pursuing innovative technologies. Substantial resources are being invested in new processes and feedstocks, and these investments are generating numerous promising pathways for producing alternative jet fuel. It is expected that commercial production of alternative jet fuel in the United States will come into operation over the next decade, but reductions in costs are necessary for this growth to be sustained.

The purpose of this handbook is to serve as a resource for airports to understand the basic characteristics of alternative jet fuels. The handbook is also intended to provide basic tools to perform an initial analysis and evaluation of opportunities for integrating alternative jet fuels into the airport setting. Readers will be able to learn about and make informed decisions regarding alternative jet fuel opportunities that may be proposed by potential suppliers, project developers, or other external entities. In addition, readers will be able to conduct internal evaluations of their airport's readiness and ability to develop alternative jet fuel projects.

The handbook presents a step-by-step methodology to systematically identify and evaluate different options for bringing alternative jet fuel to an airport. This is meant to be a high-level tool to aid in the selection of a small number of options that should then undergo a more detailed technical and business evaluation.

The successful adoption of alternative jet fuel depends on many stakeholders along the supply chain, not just airports. These include producers, distributors, and airline customers. Therefore, this handbook has been prepared taking into account the needs and interests of a wide set of stakeholders since partnerships between producers, airports, and consumers are considered key for the widespread adoption of alternative jet fuels. This handbook also provides sufficient information to understand the roles that different entities can play in the integration of alternative jet fuel into the airport setting.

How to Use This Handbook

This handbook is a guide for readers with different knowledge of and interest in alternative jet fuels. Following is a brief overview of the handbook, taking into account the familiarity of different readers with alternative jet fuels and the roles readers may play in their introduction to the airport environment:

- **Section 1: Introduction.** This section provides an introduction to alternative jet fuels, including the main reasons for pursuing them. It also identifies resources that offer further information on this topic. This section is recommended for readers with general interest and limited knowledge of alternative jet fuels.
- **Section 2: What Are the Main Characteristics of Alternative Jet Fuels?** This section is an abbreviated primer on alternative jet fuels covering the following topics:
  - Safety and certification,
  - Feedstocks (raw materials) and technologies for producing alternative jet fuels,
  - Environmental and economic benefits, and
  - Possible economic implications of regulation.

  This section is recommended for readers with general interest and limited knowledge of alternative jet fuels. Readers familiar with the fundamentals of alternative jet fuels and interested in a deeper understanding of the topics covered in Section 2 are encouraged to consult the primer included in the appendices. In addition to providing more detail on the topics covered in Section 2, the primer includes information on more technical and implementation-related aspects, including:
  - Financial considerations,
  - FAA policies and regulations,
  - Environmental reviews and permitting,
  - Energy policy, and
  - Examples of publicly announced alternative fuel projects.
- **Section 3: How Can Alternative Jet Fuels Be Integrated into the Airport Setting?** This section is intended for readers comfortable with the fundamentals of alternative jet fuels. It presents an evaluation framework that allows the analysis and evaluation of potential projects in a sequential manner. The main steps of this framework are:
  - **Stakeholder analysis:** Helps to identify the needs of the main stakeholders and how to get them involved (see Section 3.3).
  - **Initial screening of options:** Provides high-level screening criteria to reduce the large number of potential alternative fuel projects to a select few (see Section 3.4).
  - **Comparative evaluation of screened options:** Gives guidance to evaluate, compare, and further refine the selection of projects identified in the previous step (see Section 3.5).
  - **Suggested next steps:** Suggestions for continuing the work started with this handbook (see Section 3.6).

The sequential nature of the evaluation framework allows readers from airports and other readers to systematically explore the case for pursuing alternative jet fuels while developing internal capabilities in the evaluation of potential opportunities. It also allows readers to proceed according to their internal timeline and without necessarily committing significant levels of scarce resources from the start.

- **Section 4: Frequently Asked Questions.** This section presents a representative set of questions and concerns from the aviation industry and the communities they serve with respect to alternative jet fuels. It is intended as a quick reference for anyone with an interest in alternative jet fuels.
- **Section 5: Supporting Materials and Worksheets.** This section presents supplemental materials and worksheets to aid in the evaluation of alternative jet fuel projects.
- **Section 6: Bibliography.** This section presents a bibliography of material on alternative jet fuels.
- **Primer on Alternative Jet Fuels (Appendices).** The appendices present more detailed information on the different aspects of alternative jet fuels discussed in Sections 1 through 4, providing a more in-depth understanding of alternative jet fuels.

SECTION 1

Introduction

1.1 What Are Alternative Jet Fuels?

Alternative jet fuels are fuels made from nonpetroleum sources that have the same performance characteristics as today's petroleum-based jet fuels such as Jet A and JP 8. They can be produced with different technologies and from a number of different feedstocks, both renewable and nonrenewable. Renewable feedstocks include plant oils, animal fats, and biomass (e.g., crop residues, wood chips, and prairie grasses); nonrenewable feedstocks include coal and natural gas. Depending on the feedstock and technology process used, alternative jet fuels have different environmental and economic characteristics.

The location of production facilities with respect to feedstocks and end users is a key determinant of costs and, hence, the economic viability of alternative jet fuels. Therefore, it is important to consider alternative jet fuel projects in the context of their entire supply chain, as shown in Figure 1.

In addition to location, an important logistical consideration for alternative jet fuels is blending. Alternative jet fuels are currently certified and approved for use in existing jet fuel infrastructure as blends. Thus, these fuels need to be blended with conventional jet fuel prior to injection into existing pipelines, storage, and other infrastructure and equipment.

1.2 What Is Driving the Interest in Alternative Jet Fuels?

A diverse group of stakeholders, including airports, airlines, the military, and federal and local governments, want alternative jet fuels for a series of economic, operational, and environmental reasons. These reasons include:

To diversify sources of conventional jet fuel: Alternative jet fuels offer the aviation industry the potential benefit of diversifying its supply of jet fuel. Virtually all of the jet fuel currently used in aviation operations is derived from petroleum. Petroleum's limited spare productive capacity and associated volatile, steadily increasing price are key business challenges for the industry, primarily because jet fuel is one of aviation's highest cost components. By dedicating resources to alternative jet fuels, the aviation community is looking for an opportunity to diversify its fuel supply chain and introduce competition to one of its main operating cost areas.

To improve reliability and security of supply: Alternative jet fuels can incrementally secure the supply of liquid fuel to the airline industry. Given current technology, there are no practical options to power aircraft engines other than with liquid fuels. Unlike other transportation

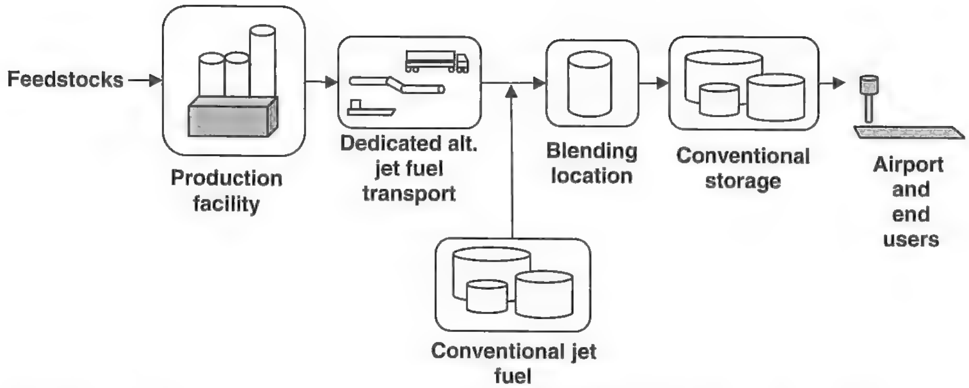

Figure 1. Schematic of the integrated alternative jet fuel supply chain.

sectors, such as ground and marine transportation, the aviation industry will be unable to switch to nonliquid energy sources such as solar, nuclear, or hydrogen to power its airplanes, at least in the near term. As competition for petroleum-based products intensifies due to increased demand from other industry sectors and the possible exhaustion of this nonrenewable resource, there are concerns that aviation may find it difficult to meet its needs of liquid fuels over time. Furthermore, alternative jet fuel production facilities need not be located in the same places where conventional refineries are located. This would allow the geographic diversification of production away from sites prone to natural disasters, such as the U.S. Gulf Coast.

To enhance energy security: The United States is the largest net importer of petroleum. These import supplies are subject to disruption because of regional or international conflicts. As major users of petroleum-based jet fuel, U.S. airlines and the military would like to develop domestic alternatives to lessen the dependence on foreign sources. The production of alternative jet fuels using feedstocks that are available in the United States can help meet this goal.

To reduce the volatility of the price of jet fuel: Alternative jet fuels may contribute to reducing the volatility of the price of jet fuel. By diversifying the supply of jet fuel and making jet fuel less dependent on unstable foreign sources and more immune from the vagaries of financial flows in the futures markets, alternative jet fuels may lead to less variability in the price of jet fuel. Furthermore, as the alternative jet fuel industry develops, airlines may have the ability to enter into long-term supply contracts with potential producers that would specify a certain price or price band over time.

To provide regional economic benefits: Alternative jet fuels have the potential to generate new jobs and spur economic activity, especially in rural areas where feedstocks can be grown. In addition, the growth of a domestic alternative fuels industry would help reduce U.S. imports of foreign crude, and thus those resources that would otherwise be spent abroad could be re-invested domestically. Alternative jet fuels can also mitigate the economic impact of carbon taxes or other charges under consideration for conventional jet fuel.

To provide potential environmental benefits: As a user of petroleum-based fuels, aviation is a source of carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM). The introduction of alternative jet fuels can potentially help reduce aviation's environmental footprint, providing benefits to the airports, their surrounding communities, and the airlines they serve.

1.3 Why Are Airports Interested in Alternative Jet Fuels?

Airports can specifically benefit from alternative jet fuels for the following reasons:

Improvements to local air quality: As mentioned before, alternative jet fuels have the potential to provide benefits in terms of reduced emissions of local air quality pollutants, such as NO_x, SO_x, and PM, compared to conventional jet fuel. This is of particular interest to airports that operate in air quality non-attainment areas, which means that they are operating or trying to build something in an area with air quality that does not conform to federal or state standards of acceptability with respect to various pollutants.

Being a good citizen: As vital members of the community and important players in the local economy, airports want to actively contribute to the well-being of the communities they serve. Many airports are already making changes along the lines of being more environmentally conscious by, for example, introducing electric-powered vehicles, building more energy-efficient buildings, and modernizing firefighting training facilities. The introduction of alternative jet fuels offers airports an opportunity to further their efforts to create a positive impact.

Serving their airlines' needs: Airports may have an opportunity to play an enabling role for sourcing and distributing alternative jet fuels to interested airlines. Furthermore, the availability of alternative jet fuel at an airport may attract additional air service from parts of the world that are particularly sensitive to environmental issues. This may lead to incremental business for the airports.

1.4 What Roles Can Airports Play in Alternative Fuel Projects?

There are a number of ways in which airports can be involved with alternative jet fuel projects. Before describing those roles, however, it is useful to briefly describe how airports are currently involved in the sourcing of conventional jet fuel. Airports ensure that safety and regulatory requirements of fuel handling and storage are met but are not typically involved with commercial aspects of fuel sourcing. The supply of jet fuel at airports is typically the responsibility of airlines that enter into contracts with oil companies, third-party suppliers, or fixed-based operators (FBOs). Furthermore, the jet fuel infrastructure at airports is typically managed and maintained by third-party vendors on behalf of the airports or airlines. Thus, the sourcing and handling of jet fuel is usually not part of an airport's core business.

In the case of alternative jet fuels, however, there are opportunities for airports to get involved and be supportive of projects. While it is not currently expected that airports would take the lead and be the main project developer, there are multiple ways in which they can participate and offer support. For example, airports can:

- Help obtain support from local and regional authorities;
- Facilitate partnerships with feedstock producers, alternative jet fuel producers, airlines, and other stakeholders;
- Conduct studies to identify the feasibility of introducing alternative jet fuels; and
- Provide direct support, such as the use of airport property for construction of storage and other infrastructure that may be required.

The kind of support that airports provide will depend greatly on the specific conditions and governing structure of each airport. Because this is such a new and maturing field, airport roles are likely to differ from site to site, but any contribution will be significant to get this industry

off the ground. Furthermore, innovative airports can look at alternative jet fuels as another means of new business development while at the same time supporting the airlines, being a good citizen, and helping improve the environment.

A follow-on ACRP project, ACRP 02-36, "Assessing Opportunities for Alternative Fuel Distribution Programs," will investigate opportunities for airports to introduce a broader variety of alternative fuels, such as green diesel and compressed natural gas (CNG), in addition to alternative jet fuel. This expanded scope should be of great interest to airports as they operate their own ground vehicles and other equipment, such as back-up generators, that can use these alternative fuels. For more information on this project, please visit http://www.trb.org/ACRP/ACRP.aspx and search for ACRP Project 02-36.

1.5 Limitations of the Handbook

The field of alternative jet fuels is advancing very rapidly. The information contained in this handbook about the technologies and feedstocks to produce alternative jet fuels reflects the best knowledge as of the date of publication and is expected to be relevant in the short term. New technologies and feedstocks are expected to become available in the medium to long term; however, given the large uncertainties surrounding these developments, it is not practical to attempt to discuss them in this handbook. The evaluation and tools developed in this handbook are expected to remain relevant despite new developments on the technology front.

1.6 Resources for Further Information

The latest information about the development of alternative jet fuels can be obtained from the following sources:

- The Commercial Aviation Alternative Fuels Initiative (CAAFI, www.caafi.org), a coalition of U.S. government agencies, manufacturers, airlines, and airport organizations.
- The Air Transport Association of America (ATA, www.airlines.org), the leading trade association for U.S. airlines.
- The International Air Transport Association (IATA, www.iata.org), an international airline trade association.
- The Air Transport Action Group (ATAG, www.atag.org), an association that represents all sectors of the international air transport industry.
- The Sustainable Aviation Fuel Users Group (SAFUG, www.safug.org), a coalition of airlines, manufacturers, and other organizations involved with alternative jet fuel.
- Airport Cooperative Research Program (ACRP, http://www.trb.org/ACRP/ACRP.aspx), which supports a portfolio of projects on alternative fuels.

SECTION 2

What Are the Main Characteristics of Alternative Jet Fuels?

This section discusses the main characteristics of alternative jet fuels. These characteristics include safety, feedstocks, production technologies, environmental and economic benefits, and the regulatory environment.

2.1 Safety and Drop-in Characteristics of Alternative Jet Fuels

Are alternative jet fuels safe for use in airplanes and with other elements of the existing jet fuel infrastructure?

Yes. For alternative jet fuels, safety and compatibility with existing aircraft, engines, and other elements of the jet fuel infrastructure are of critical importance. Current efforts to certify the use of alternative jet fuels are based on the principles that they meet or exceed the same safety criteria as conventional jet fuel and that they are 100% compatible with the existing jet fuel infrastructure.

Who is responsible for setting the standards to certify conventional and alternative jet fuels?

The specifications for jet fuel in the United States and around the world are established by standard-setting organizations such as ASTM International and the United Kingdom's Ministry of Defence Standards (DEFSTAN). The role of the FAA and other safety organizations is to establish ground rules for the standard-setting organizations to use. Aircraft manufacturers, airlines, and airports refer to the ASTM and DEFSTAN standards when designing, operating, and maintaining aircraft.

What are drop-in alternative jet fuels?

There is no formal definition of or standard for drop-in alternative jet fuels. Informally, a drop-in fuel is one that is fully interchangeable with petroleum-based fuels complying with ASTM or DEFSTAN standards. This drop-in interchangeability must be possible throughout the entire product distribution cycle—from refinery to aircraft. This includes the intermediary distribution steps: pipelines, tank farms, and fuel trucks. By definition, drop-in alternative jet fuels can use the same infrastructure as conventional jet fuel, thus avoiding the need to build expensive duplicate infrastructure.

Characteristics of drop-in alternative jet fuels must be equivalent to those of petroleum-based jet fuel (within the ranges established by standards for petroleum-based jet fuel). These characteristics include a number of elements such as safety (freeze point, flash point), performance (heating value and density), wear on fuel systems, and electrical conductivity.

Are there examples of drop-in alternative jet fuels?

Synthetic paraffinic kerosene (SPK) is the best example of a drop-in alternative jet fuel. SPK is considered a drop-in alternative jet fuel because it meets the technical and safety properties of conventional jet fuel—except for aromatic content. Aromatics are complex hydrocarbon compounds that are required to be present in any jet fuel to some minimal amount (currently 8%). The existing jet fuel distribution, storage, and handling infrastructure has been designed with aromatics in mind. Without aromatics, rubber seals in valves and other elements of the jet fuel supply infrastructure can leak and present unacceptable environmental and safety issues. Therefore, to be considered as a drop-in alternative jet fuel, SPK must be mixed with conventional jet fuel so that the resulting blend contains the amount of aromatics mandated by the jet fuel specification.

To date, blends of up to 50% of two types of SPKs have been approved and certified as drop-in alternative jet fuel. One type includes SPKs made out of coal, gas, biomass, or municipal solid waste (MSW) using the Fischer-Tropsch (FT) process. The other type of SPK includes hydroprocessed esters and fatty acids (HEFA) made from plant oils and animal fats. HEFA is also referred to as hydrotreated renewable jet (HRJ). Both the FT and HEFA processes will be discussed further in Section 2.3.

What are the blending requirements for alternative jet fuels?

As discussed previously, current approval of alternative jet fuel for use in aircraft requires that they be blended with conventional jet fuel up to a concentration of 50% alternative jet fuel. As new processes for producing alternative jet fuels are developed and more experience with the handling of existing alternative jet fuels is obtained, it is possible that the blending requirements could be reduced.

Have alternative jet fuels been used in aircraft?

Yes. Jet fuel made from coal using the Fischer-Tropsch process has been in daily use for scheduled airline service in South Africa for more than 20 years. The South African energy and chemical company Sasol has produced SPK and other chemicals from locally sourced coal using its proprietary version of the FT process. When blended up to 50% with conventional jet fuel, Sasol's SPK was approved for use as commercial jet fuel under the U.K.'s DEFSTAN 91-91 in 1998. Since 1999, this jet fuel blend has been used successfully by commercial airlines in aircraft refueled at South African airports, and since then South African Airlines has experienced no fuel-related problems (Roets 2009).

Prior to qualification, there were numerous examples of commercial flight tests using alternative jet fuels made with different technologies and feedstocks. A summary of flight demonstrations in commercial aircraft is shown in Table 1. The flight tests showed no significant difference in the performance of the alternative jet fuel compared to conventional jet fuel.

Since the qualification of HEFA on July 1, 2011, KLM, Lufthansa, and Aeromexico have initiated commercial service using fuels purchased from U.S. and European sources. These flight commitments for extended commercial use will prove HEFA fuel's service reliability. Flights by the airlines Thomson (UK charter operator) and Finnair are imminent.

2.2 Feedstocks for Producing Alternative Jet Fuels

What feedstocks can be used to produce alternative jet fuels?

The two primary sources of feedstock for alternative fuels are fossil fuels and bio-derived feedstocks. Fossil fuel feedstocks include coal and natural gas. Bio-derived feedstocks include

Table 1. Alternative jet fuel flight demonstrations in commercial aircraft.

Date	Airline or Other Sponsor	Aircraft	Engine Maker	Fuel Producer	Feedstock	Technology	Source
Feb 2008	Airbus	A380	Rolls-Royce	Shell	Natural gas	Fischer-Tropsch	Airbus 2011
Dec 2008	Air New Zealand	B747-300	Rolls-Royce	UOP	*Jatropha*	HEFA	Warwick 2009
Jan 2009	Continental	B737-800	GE/CFMI	UOP	*Jatropha*, algae	HEFA	DOE 2009
Jan 2009	Japan Airlines	B747-300	Pratt & Whitney	UOP	*Camelina*, *Jatropha*, algae	HEFA	Mecham 2008
Oct 2009	Qatar	A340-600	Rolls-Royce	Shell	Natural gas	Fischer-Tropsch	Qatar Airways 2011
Nov 2009	KLM	B747-400	GE	UOP	*Camelina*	HEFA	North Sea Group 2011
Apr 2010	United	A319	IAE	Rentech	Natural gas	Fischer-Tropsch	Kuhn 2009
Nov 2010	TAM	A320	CFMI	UOP	*Jatropha*	HEFA	Karp 2010
Apr 2011	InterJet (Mexico)	A320	CFMI	UOP	*Jatropha*	HEFA	Gross 2011
June 2011	Honeywell	G450	Rolls-Royce	UOP	*Camelina*	HEFA	Chatzis 2011
June 2011	Boeing	B747-8	GE	UOP	*Camelina*	HEFA	Lane 2011
July 2011	Lufthansa	A321	CFMI	Neste Oil	Palm oil, rapeseed, animal fats	HEFA	Reals 2011
July 2011	KLM	B737-800	CFMI	Dynamic Fuels	Used cooking oil	HEFA	KLM 2011
July 2011	Finnair	A319	CFMI	SkyNRG	Used cooking oil	HEFA	Mroue 2011
Aug 2011	Aeromexico	B777-200	GE	ASA	*Jatropha*	HEFA	Aeromexico 2011
Sept 2011*	Thomson Airways	B757	Rolls-Royce	SkyNRG	Used cooking oil	HEFA	Thompson 2011
2012*	Porter Airlines	Bombardier Q400	PWC	UOP	*Camelina*	HEFA	Bombardier 2010
2012*	Azul	Embraer	GE	Amyris	Sugarcane	FRJ	Advanced Biofuels 2009
2013*	Air China	B747-400	Pratt & Whitney	UOP	*Jatropha*	HEFA	Stanway 2010

*Announced as of August 31, 2011

plant oils, animal fats, crop residues, woody biomass, municipal solid waste, and other organic material. Each has relative strengths and weaknesses. Following is a brief overview of each potential feedstock and the most important considerations for each.

1) **Fossil fuels**

Coal and natural gas can be used to make alternative jet fuel with the Fischer-Tropsch process (see Section 2.3). Because of availability, transportation systems, and developed markets, coal and natural gas can support production in commercial quantities.

a) **Sources and availability**

Ample supplies of coal and natural gas at low per-unit costs support large rates of extraction for sustained periods of time. Costs and methods for extraction are well known, and large untapped deposits exist in the United States.

b) **Economics and logistics**

Coal and natural gas have well-developed markets, supply chains, pricing mechanisms, and risk management tools such as financial derivatives to hedge against volatility in the price of the commodities. Existing pipeline and rail transportation systems are cost effective and cheaper than truck transportation for transporting coal and natural gas; however, alternative jet fuel processing facilities would need to be located in proximity to existing transportation infrastructure in order to take advantage of this cost advantage. Construction of new rail lines and pipelines would likely compromise the economic viability of any alternative jet fuel project.

c) **Environmental considerations**

If not properly mitigated, the life-cycle greenhouse-gas (GHG) footprint of alternative jet fuels from fossil fuel feedstocks can be two to three times that of conventional jet fuel (see Box 1 and Section 2.4 for more details on life-cycle GHG analysis). These results depend to a great extent

Box 1. Brief introduction to life-cycle greenhouse gas analysis.

Life-cycle analysis (LCA) of GHGs estimates the amount of greenhouse gases (e.g., CO_2) released in the full life cycle of an alternative fuel (see Section 2.4 for a more complete discussion). This includes emissions from the production, distribution, and combustion of an alternative fuel, including extraction; inputs to production such as tillage, planting, and harvesting biomass feedstocks; processing and conversion; transportation; and storage. It is a cradle-to-grave estimate of all GHG emissions from the production of the fuel.

A key concept in life-cycle GHG analysis is land use change (see Section 4 for more information on land use). Land use change can lead to indirect GHG emissions. For example, increased demand for feedstocks that compete for land with the existing food and feed production chain (e.g., corn, soybeans) may lead to conversion of unused land, such as grassland or forests, to agriculture production. This can result in an increase in CO_2 emissions that would be included in the life-cycle GHG analysis. Thus, LCA results can show a significant increase in GHG emissions for alternative fuels made from renewable feedstocks because of indirect land use change. Inclusion of indirect land use changes in life-cycle analysis is currently a controversial and politically charged debate.

on the efficiency of the process to convert coal or natural gas to alternative jet fuel. However, there are ways to reduce the GHG footprint. For example, carbon capture and sequestration (CCS) technology could be employed to capture and permanently store CO_2 during the production process (see Section 2.3). In addition, using biomass in addition to coal can reduce the GHG footprint of the overall process.

d) Advantages

Fossil fuel feedstocks are abundant and available at relatively low cost. Their large-scale availability is an advantage for FT plants, which tend to be very large (and expensive to build) in order to benefit from economies of scale.

e) Disadvantages

Fossil fuel feedstocks may have a potentially unacceptable life-cycle GHG footprint if not mitigated properly. Possible mitigation strategies include the use of CCS technology and use of biomass as a co-feedstock for the FT process. FT plants tend to be very large and capital intensive. For example, a typical FT plant could process 1 to 2 billion gallons per year (GPY) and cost several billion dollars to build. For comparison, the average size of the top 100 U.S. petroleum refineries is 2.5 billion GPY (EIA 2011). In addition, since there are not many commercial-scale examples in operation, it is difficult to evaluate their economics of production.

2) Oils and fats

Plant oils and animal fats can be used as feedstocks for making alternative jet fuels via hydroprocessing (see Section 2.3).

a) Sources and availability

Many different plant oils can be used to make alternative jet fuel. These include nonfood oils such as *Camelina, Jatropha,* pennycress, and algae, and food oils such as soybean and canola. Some of these oils are currently produced at commercial or semicommercial scales in the United States. Others have not yet reached such large scales of production. Research is ongoing to improve the oil content (yields) and other characteristics that are advantageous to alternative jet fuel production. Animal fats (tallow), frying oils, and greases may also be used to produce alternative jet fuel.

Nonfood oils are promising potential feedstocks with attractive characteristics. Algae are adaptable, grow very quickly, and have higher oil content than other alternative fuel feedstocks. *Jatropha,* an oilseed plant historically grown in tropical areas, has high concentrations of oil and can be grown in poor-quality soils not suitable for traditional agricultural crops. Pennycress and *Camelina* have high oil content and have the potential to be grown without competing for land availability with traditional crops.

Tallow and other fats are generally considered waste products, so these materials are more economically attractive than refined plant oils; however, the current poor refining quality may require additional processing or additives.

b) Economics and logistics

Feedstock is expected to be the largest cost component in the production of alternative jet fuel from plant oils. Some plant oils that could potentially support commercial-scale production of alternative jet fuel, such as soybean oil, are already expensive to produce. In addition, because soybean and other plant oils are also used for human and animal consumption and in the production of biodiesel, competition for this feedstock is likely to keep prices high. Therefore, there is great interest in alternative oilseed feedstocks such as *Jatropha,* pennycress, and *Camelina* that can be produced at a lower cost.

Soybean oil and other oilseed feedstocks have well-developed markets, available risk management tools, and well-developed supply chains. Alternative oil feedstocks such as algae and *Jatropha* may be able to be integrated into the existing transportation infrastructure. Markets, pricing mechanisms, risk management tools, and contract and supply chain considerations would all have to be developed for algae, *Jatropha,* and other feedstocks not currently produced at commercial scale. Transportation and storage of tallow can be expensive, requiring heated tanks at a minimum of 65°C to thwart the growth of bacteria and enzymatic activity.

c) Environmental considerations

Alternative jet fuels from plant oils and fats may have a lower life-cycle GHG footprint compared to conventional jet fuel; however, the life-cycle GHG footprint of alternative jet fuels from plant oils is very dependent on land use. If the plant oil is grown on existing cropland, the land-use change impact may be limited; however, if forest needs to be cleared to grow the plant oil, the land-use impact would be significant. Plant oils that can grow in fallow or marginal lands, such as *Jatropha* and *Camelina,* can avoid some of these concerns.

d) Advantages

Some plant oils are available in commercial quantities and have developed markets, supply chains, and transportation systems. Some alternate feedstocks have great potential. Some strains of algae have the potential to produce more than 30 times the amount of oil per acre per year than any other plant currently used to produce alternative fuels. The relatively small size of HEFA facilities makes co-location near airports possible.

e) Disadvantages

All current oil-based alternative jet fuels struggle with high costs. Improving the productivity of growing oil plants is critical to achieve competitive costs for alternative jet fuel. Feedstock costs make up 80% or more of the cost of these fuels. The U.S. Department of Agriculture (USDA) has programs to improve yields that are similar to food crop yield improvement programs. Similarly, current production yields for algae are not yet commercially viable and are still in the research stage. Fuels derived from edible plant oils could be considered to compete with food supplies (see Section 4.1 for more information on the food-versus-fuel question).

Tallow-based oils enjoy a steady if limited supply, but storage and transportation issues may constrain their use as a feedstock. Furthermore, their limited supply may constrain their use on a large-scale commercial basis.

3) Biomass feedstocks

Biomass feedstocks are generally divided into three categories: energy crops (e.g., switchgrass), agricultural residues (e.g., corn stover), and woody biomass (e.g., wood chips). The potential supply of biomass is substantial, although there are considerable constraints related to its bulk. Biomass can be used with the Fischer-Tropsch process to produce alternative jet fuel (see Section 2.3).

a) Sources and availability

Energy crops are grown specifically and primarily for biofuels, including alternative jet fuel. Switchgrass, *Miscanthus,* energy cane, wheatgrass, and bluestem are potential energy crops. Agricultural residues such as corn stover and wheat straw are other promising sources of biomass feedstock for alternative jet fuel production. Woody biomass and by-products are also potential feedstocks. The lumber, mill, pulp, and paper industries have long burned woody by-products as a source of energy and consume most available supplies. Recent declines in these industries, however, are driving down the costs of woody biomass and spurring interest in its use for producing alternative jet fuel.

b) Economics and logistics

Energy crops need to be grown on marginal lands not appropriate for traditional agriculture production in order to keep feedstock costs low. Absent production on marginal lands, energy crops will have to compete for land use with current agriculture production activities and provide a return to producers at least equal to current production. Agriculture residues such as corn stover and wheat straw have an economic advantage over dedicated energy crops because they are by-products of corn and wheat production. Even though the production costs of agricultural residues are already covered by existing revenues, producers will likely require additional incentives as compensation for harvest, collection, and transportation costs. Furthermore, agricultural residues have soil quality benefits such as nutrient cycling and moisture retention; accordingly, not all agriculture residues could be collected.

There are many challenges associated with the use of dedicated energy crops and agriculture crop residues as alternative fuel feedstock. No established markets exist, and contracting and supply chain considerations would have to be resolved before producers would be willing to supply either a dedicated energy crop or agricultural residues.

The huge quantities of biomass required to support commercial-scale operations make transportation and logistical issues very challenging. Densification and pretreatment techniques to address these issues are being studied. Woody biomass not currently utilized for other products and processes, such as harvest residues, faces logistical challenges similar to crop residues and energy crops due to low bulk density.

c) Environmental considerations

Land use can have a bearing on the life-cycle GHG footprint of alternative jet fuels made from biomass feedstocks. In order to prevent competing uses for land, dedicated energy crops will need to be grown on land that is marginal for traditional agriculture. What constitutes marginal land, what crops would be grown, and the practicality of production of dedicated energy crops will vary regionally. Research is ongoing to identify how much marginal land is available. Research on cultivation, yield, and production economics of various potential dedicated energy crops is also ongoing. Assuming no changes in land use, the life-cycle GHG footprint of alternative jet fuels from biomass can be less than that of conventional jet fuels.

d) Advantages

Energy crops may be able to grow on land not suitable for traditional agriculture, are adaptable to various soils and climates, and integrate well with conventional agriculture. The use of marginal land for energy crops eliminates the competition with land for traditional agriculture commodities, reduces production costs, and avoids food-versus-fuel concerns. Agriculture residues may be available in sufficient quantities to potentially support a commercial conversion facility. Corn stover and wheat straw have the greatest potential as low-cost, first-generation biomass feedstocks.

e) Disadvantages

Logistical and transportation challenges are a major impediment. Because of their low energy density, very large amounts of biomass feedstocks are required to feed production facilities. Handling this bulky material can be expensive and uneconomical outside of a 50-mile radius from the production facility. Market, supply chain, contracting, transportation, and logistical infrastructure need to be developed. Furthermore, there are concerns about how much forest and other residue can be extracted for fuel production without adverse impacts (SAFNW 2011b).

4) Municipal solid waste

a) Sources/availability

MSW includes a wide array of discarded materials such as residential and commercial garbage, plastics, textiles, wood, yard trimmings, and food scraps. In some areas, MSW can also include nonsolid materials such as sludge from wastewater treatment plants. Depending on the type of solid waste used as feedstock, different technologies can be used to produce liquid fuels. For example, wood and yard trimmings can be used with FT processing facilities, while waste oils can be used in HEFA processing facilities.

b) Economics and logistics

Once recyclables are removed, waste-to-energy providers and landfills compete for the remaining MSW. Depending on the locality, MSW generators may pay for its disposal. In some instances, however, depending on the market structure and scarcity value of the waste, MSW generators may receive payment for access to their waste. Because of MSW's bulk, an alternative jet fuel processing plant would need to be sited close to existing waste flows. MSW may need to be preprocessed to convert it into feedstock. While the preprocessing technology exists, it adds cost to the entire process.

c) Environmental considerations

The environmental effects of MSW-based fuels vary significantly based on the contents of the waste. Therefore, the environmental effects could be minimized by the removal of various items down the waste stream. For example, if an objective is to maximize life-cycle GHG footprint reduction, then plastics and tires can be left out of the feedstock. If an objective is to eliminate or reduce the use of landfills, plastics and tires can be included in the feedstock, although this would suboptimize the potential life-cycle GHG reduction.

d) Advantages

Municipalities may recapture some of their waste collection costs by selling MSW to refiners. In addition, using MSW can reduce the need for landfills and decrease methane and other greenhouse gasses typically associated with MSW in landfills.

e) Disadvantages

There are several challenges to using MSW as a feedstock, including consistency and reliability of supply, proximity of waste to the conversion facility, sorting, and preprocessing. The potential perception that an MSW-based alternative jet fuel plant and the accompanying transportation infrastructure degrade the local municipal environment must also be addressed. Furthermore, it needs to be noted that some may perceive use of MSW for fuel as competing with existing recycling programs by diverting waste that would otherwise be recycled to fuel production.

5) Summary comparison of feedstock characteristics

Table 2 presents a summary of feedstock characteristics.

2.3 Technologies for Producing Alternative Jet Fuels

What technologies can be used to produce drop-in alternative jet fuels?

There are currently two main technologies for producing drop-in alternative jet fuels: the FT process and hydroprocessing. FT can be used to turn coal, natural gas, or biomass into liquid fuels, including alternative jet fuel and diesel. Hydroprocessing uses a process similar to conventional

Table 2. Summary comparison of feedstock characteristics.

Feedstock		Sources/Availability		Economics and Logistics			Environmental and GHG Benefits
		Supply	Extraction and Cultivation	Cost	Markets, Pricing Mechanisms	Supply Chain Logistics	
Fossil fuels	Coal	Abundant; feedstock supply scalable to match commercial conversion facility.	Well developed	Low	Well developed	Well developed	Without CCS, GHG footprint may be greater than for conventional fuels.
	Natural gas	Abundant; feedstock supply scalable to match commercial conversion facility.	Well developed	Low	Well developed	Well developed	GHG footprint less than conventional fuels with CCS; similar or greater without CCS.
Oils and fats	Nonedible oils (e.g., *Camelina*, *Jatropha*, pennycress, algae)	Current supplies are tight and very competitive. Need significant increase in acres cultivated to support commercial conversion facility.	Developing quickly; on-going research needed to increase yields.	Currently high; expected to decline with yield improve-ments.	Not mature; expected to develop as feedstock availability increases.	Can use existing infrastructure for commercial oils available today.	Potential for lower GHG carbon footprint than conventional fuels depending on land-use change assumptions.
	Edible oils (e.g., soybean, canola)	Tight and very competitive	Well developed	High	Well developed	Well developed	Potential for lower GHG carbon footprint than conventional fuels depending on land-use change assumptions.
	Animal fats (tallow), frying oil, greases	Steady but finite supply	Well developed	Medium to low	Well developed	Well developed	Potential for lower GHG carbon footprint than conventional fuels.
Biomass	Energy crops	Potentially abundant	Still in research and develop-ment stage.	Still in research and develop-ment stage	Not mature; expected to develop as feedstock availability increases.	Low energy density of bulky biomass makes logistics challenging to support commercial scale.	Potential for lower GHG carbon footprint than conventional fuels depending on land-use change assumptions.
	Agricultural residues	Abundant; type and availability varies considerably based on geographic region.	Well developed with research ongoing to address bulk density issues.	Low	Not mature; expected to develop as feedstock availability increases.	Low energy density of bulky biomass makes logistics challenging to support commercial scale.	Potential for lower GHG carbon footprint than conventional fuels depending on land-use change assumptions.
	Woody biomass	Must compete with current uses in pulp and paper industry.	Well developed	Medium to low	Well developed	Well developed	Potential for lower GHG carbon footprint than conventional fuels depending on land-use change assumptions.
MSW		Steady but finite supply	Well developed for some types	Medium to low	Well developed	Well developed	Potential for lower GHG carbon footprint.

petroleum refining to turn plant oils or animal fats into liquid fuels. Alternative jet fuels obtained through hydroprocessing are also known as hydroprocessed esters and fatty acids or bio-SPK fuels.

What are the main characteristics of FT and HEFA processes?

Table 3 lists the main considerations of the FT and HEFA processes.

Table 3. Main considerations of the FT and HEFA processes.

Consideration	Fischer-Tropsch SPK (FT SPK)	Hydroprocessed Renewable Jet (HEFA or bio-SPK)
Feedstock	• Biomass, coal, natural gas.	• Plant oils or animal fats.
Cost of feedstock	• Very low for biomass. • Low for coal. • Low to medium for natural gas.	• High for commercial plant oils (e.g., soybean) because of high demand. • High for plant oils not currently produced at commercial scales (e.g.,*Camelina*) but expected to decrease as scale is achieved. • Medium to low for animal fats.
Cost of feedstock gathering and logistics	• High infrastructure and procurement costs for biomass collection and transport. • Low for natural gas if connected to existing infrastructure. • Medium for coal if connected to existing infrastructure.	• Medium to high for extracting plant oils, but low for transporting plant oils with existing infrastructure. • Medium to high for animal fats.
Production costs	• Low marginal cost of production.	• Low to medium marginal cost of production.
Scale	• Very large (300 million GPY minimum, 1-2 billion GPY typical).	• Medium (7.5 million GPY minimum, 90–150 million GPY typical); production economics favor larger sizes.
Product quality	• High (meets critical jet fuel properties—such as freeze and flash points—defined in the ASTM specification). • Approved by ASTM.	• High (meets critical jet fuel properties—such as freeze and flash points—defined in the ASTM specification). • Approved by ASTM.
By-products	• Large quantities (60%–80%) of by-products: diesel, high molecular waxes, naphtha, liquefied petroleum gas (LPG).	• Moderate quantities (30%–50%) of renewable diesel, LPG, and naphtha.
Capital requirements	• Existing FT plants are very large—larger than typical crude oil refineries. Small-scale FT plants are being proposed, but typical capital investments are about $500 million for small scale (75 million GPY) and running up to billions of dollars for large scale (750 million GPY).	• Depends on scale. Smallest practical scale is about 7.5 million GPY for about $50 million; larger scale of 70 million GPY for about $250 million.
Plant area or physical footprint	• Typical refinery size footprint is 10 to 15 acres.	• Large-scale refinery is about one-tenth the size of a conventional refinery—roughly 1 to 5 acres. • Can be integrated into a conventional refinery.
Life-cycle GHG footprint	• Medium with CCS. • Very large for coal gasification without carbon CCS. • Medium for natural gas. • Low for biomass (ignoring land-use change). • Medium for biomass (including land-use change).	• Low for land-based plant oils (ignoring land use). • Very low for sea-based plant oils (e.g., algae). • Medium for plant oils (including land-use change).

What are the major factors affecting the economics of alternative jet fuel production?

The major factors affecting the economics of alternative jet fuel production can be classified in three categories: market, technology, and policy factors. Market factors reflect the dynamics of a new industry having to compete with established industries for the same resources. For example, current availability of nonfood feedstocks for alternative jet fuel production, such as forest residues, oilseed crops, and algae, is rather limited because there has not been historically significant demand for these kinds of raw materials. However, it is expected that as alternative fuels start to expand, more quantities and types of feedstock will become available. As the supply chains for these feedstocks mature, their costs are projected to fall. At the same time, alternative jet fuel production will face competition from other alternative fuels (e.g., biodiesel) for the same nonfood feedstocks and other inputs (e.g., labor, land, water, industrial supply chains). Another important market factor is the cost of alternative jet fuel with respect to conventional fuel. If the price of crude oil and carbon increases as forecasted by some, alternative jet fuel will become more competitive.

Technology factors are related to processes available for producing alternative jet fuels and how their costs are expected to change over time. The FT and HEFA technologies provide a near-term opportunity for commercial production of alternative jet fuel. As these technologies improve, become more efficient, and scale-up, processing costs are expected to decrease. Furthermore, new facilities are expected to have lower operating costs due to the more efficient use of natural gas and other inputs. A similar cost-reduction progression is expected for new production processes that are still in research and development.

Finally, policy and government action can have a significant impact on the costs of alternative jet fuels. In the United States there are a series of mandates, taxes, and tariffs on alternative fuels, including the Renewable Fuel Standard 2 (RFS-2) and other mechanisms discussed in Section 2.6. All of these mandates and regulations can greatly influence the economics of alternative jet fuels. Moreover, the military is considering various ways to support the development of alternative jet fuel supplies, including the provision of funding for facilities, long-term purchase agreements, and the possibility of fuel pricing that is not tied to that of petroleum-based fuel. Therefore, it is important for all stakeholders of alternative jet fuel projects to understand how government action can affect them, positively or negatively.

It is important to point out that capital requirements and operating costs for any facility will be dependent on local conditions such as access to feedstocks and labor, site conditions, and what utilities are already in place. For example, space adjacent to an existing processing facility is advantageous due to utilities typically being in place and the advantage for creating a mixing point on-site.

Are there other pathways for producing alternative jet fuels?

Many research and development (R&D) sources are pursuing so-called "advanced process" pathways, with the goal of ASTM qualification in the 2013 to 2015 time period. While the qualification authorities are in the process of deciding how many independent pathways to pursue, as of this writing, there are three fundamental approaches under consideration:

1. **Advanced fermentation to jet (FTJ),** using biological organisms that turn feedstocks directly into finished products,
2. **Catalytic to jet (CTJ),** using nonbiological agents that produce alcohols, which can then be processed into alternative jet fuel, and
3. **Pyrolysis oil to jet (PTJ),** which converts cellulosic feedstocks into a bio-crude that can be used to produce alternative jet fuel.

These processes are characterized by the fact that they can utilize a broad variety of bio-based feedstocks, including cellulosic materials. The potential for a large supply of possible feedstocks

increases the chances that these technologies can reach commercial scale and add significant production to the alternative jet fuel supply pool. Furthermore, production costs for these technologies are mostly driven by process maturity instead of feedstock cost, which is the case for HEFA.

These technologies are still in the early stages of R&D and have yet to be tested in actual aircraft. As of this writing, flight programs are planned for both FTJ and CTJ. In the case of FTJ, a program is planned in Brazil in 2012 (see Table 1). In the case of the CTJ, the U.S. Air Force is teamed with Swedish Biofuels to execute a flight program on a Gripen fighter aircraft in 2014. Based on the pace of R&D and ASTM qualification activities as proven by the FT and HEFA experience, these fuels could be qualified in the 2013 to 2015 time period. Readers are advised to review the resources listed in Section 1.6 to stay current with these developments.

How water intensive is the production of alternative jet fuel?

Water use is a topic that frequently comes up during the discussion of alternative jet fuels. Depending on the specific way in which feedstocks are recovered and processed, water consumption for the production of alternative jet fuels may be comparable to or larger than the water amounts required for conventional jet fuel production (Stratton, Wong, and Hileman 2010).

The water impact of alternative jet fuels should be evaluated by considering the feedstocks and conversion technologies separately. There are two water components pertaining to feedstocks: consumption and pollution. In terms of water consumption, traditional feedstock crops, such as soybeans, require large amounts of freshwater. In contrast, new bio-derived crops, such as switchgrass, do not need irrigation. Nontraditional crops like *Camelina* and *Jatropha* can grow in arid areas. Algae can grow in brackish water or seawater, which would limit the consumption of freshwater; however, freshwater needs also depend on the specific process used for algae growth and processing. In terms of water pollution, fossil feedstocks and traditional feedstock crops contribute runoff from fertilizers and pesticides.

Regarding conversion technologies, the need for cooling is what drives water impact. The impact varies widely, from extensive to minimal, with the type of cooling and conversion technology. FT requires substantial cooling and is generally more water intensive than hydroprocessing per unit of energy produced. The water use of a HEFA facility is less than that of a Fischer-Tropsch facility. HEFA production involves the use of hydrogen, which in combination with the oxygen present in plant oil feedstocks produces net water from the process chemistry.

What is carbon capture and sequestration?

Carbon capture and sequestration involves capturing the gaseous CO_2 released during a production process and storing it or converting it into other carbon compounds that are not released into the atmosphere. CCS technologies are being explored for manufacturing processes in which CO_2 would be released into the atmosphere, such as the FT process to make alternative jet fuel. CCS will help lower the life-cycle GHG footprint of alternative jet fuels by preventing CO_2 in the processing stage from being released into the atmosphere. Enhanced oil recovery, a process in which CO_2 is injected into oil fields, is a known technology for carbon sequestration that has been used for decades (DOE 2011a). Research is being conducted to find more efficient means of capture, storage, and conversion. These include algal systems that could potentially convert the gaseous carbon dioxide into carbon-based compounds and carbon-based oils through photosynthetic activity.

2.4 Environmental Benefits of Alternative Jet Fuels

What are the potential environmental benefits of alternative jet fuels?

This handbook focuses on two main potential environmental benefits of alternative jet fuels. First, the overall life-cycle GHG footprint may be lower than that of conventional jet fuel. Second,

PM emissions may be lower. Reductions in NO_x have been documented for alternative ground fuels relative to conventional diesel fuel, but there is currently no evidence to suggest that the same benefit extends to alternative jet fuels. The following sections discuss the GHG and PM benefits.

What are the potential life-cycle greenhouse-gas benefits of alternative jet fuels?

Compared with petroleum-based jet fuel, alternative jet fuels may have a lower GHG footprint when the entire life cycle of the fuel is considered. Life-cycle analysis (LCA) as it applies to jet fuel consists of estimating the amounts of various substances produced (or consumed) during the complete process of obtaining and using the fuel. This process is broken down into various stages as the fuel is transformed from its raw form, transported, and used. Appendix E contains a more detailed description of the life-cycle GHG analysis process.

When reviewing the detailed LCA, consider the following observations:

- The results depend greatly on the feedstock and the processing pathway to jet fuel;
- There is substantial uncertainty in the impacts of land-use change, and this drives uncertainty in the overall GHG footprint; and
- Best practices for such analysis are still evolving, particularly with regard to social equity (e.g., fuel-versus-food impacts).

Are there estimates of life-cycle GHG footprints for different alternative jet fuel pathways?

In order to illustrate the range of estimates that might be expected, we include results from a recent report (Stratton, Wong, and Hileman 2010) that analyzed several pathways to drop-in aviation fuels requiring no alterations in aircraft or storage facilities. Figure 2 shows the life-cycle GHG emissions for various combinations of feedstocks relative to conventional jet fuel.

As Figure 2 shows, depending on assumptions (particularly those associated with land-use changes associated with growth of the feedstocks), these pathways were estimated to have life-cycle GHG emissions ranging from less than 1% of the conventional crude petroleum pathway to over 8 times greater than this pathway. Several pathways have estimated life-cycle GHG emissions that are less than half of that of crude to conventional jet fuel (switchgrass to FT fuel, *Jatropha* oil to HEFA, and *Salicornia* to HEFA and FT fuel).

What are the potential benefits of alternative jet fuels with respect to local air quality?

Another potential benefit of using alternative jet fuels is the reduction in emissions that affect local air quality, in particular SO_x and PM. These emissions can lead to respiratory diseases such as asthma, and they are major contributors to acid rain, smog, and reduced visibility.

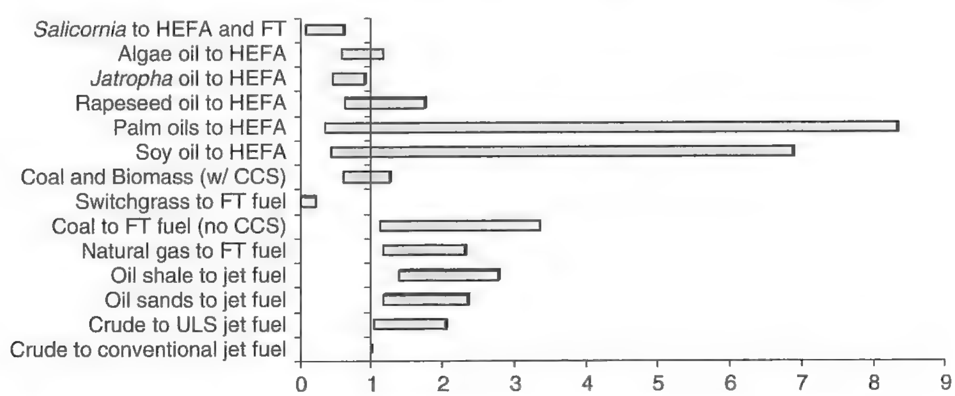

Figure 2. Relative life-cycle GHG emissions of several pathways for alternative jet fuels (conventional jet fuel = 1.0; adapted from Stratton, Wong, and Hileman 2010).

Sulfur oxides in jet fuel are precursors and indicators of particle and $PM_{2.5}$ formation. $PM_{2.5}$ is known to cause serious health problems and is regulated with separate standards by the EPA. Furthermore, as a criteria pollutant, high levels of $PM_{2.5}$ can lead to areas being designated as non-attainment zones (see Section 2.6.1), with potential negative consequences to growth and operations at airports in such areas. Ultra-fine particles (UFP) are another pollutant of concern. While there are currently no standards regulating UFP, it is possible that they will be subject to regulation in the future. Alternative jet fuels may also potentially provide benefits with respect to UFP emissions.

Alternative jet fuels are essentially sulfur-free, and tests by the U.S. Air Force indicate that their $PM_{2.5}$ contribution is significantly lower than that of conventional jet fuel.

2.5 Economic Benefits of Alternative Jet Fuels

Since there is an adequate amount of research and field experience to demonstrate the actual economic benefits of alternative jet fuels produced from agricultural feedstocks, the discussion that follows focuses on facilities that use those feedstocks. Nevertheless, the essential analytical principles can apply to studies for nonagricultural feedstocks such as coal and natural gas.

What are the economic benefits of alternative jet fuels?

Alternative jet fuel projects have the potential to bring significant benefits in terms of job creation and economic activity to the places where the processing facilities are located. Processing a commodity contributes to the local or regional economy to the extent that local inputs are used. Examples include payments for these inputs, such as wages and salaries; payments for locally purchased supplies, materials, and utilities; and possibly payments to local financial institutions. These initial local expenditures are direct impacts that set in motion rounds of spending and re-spending that result in secondary impacts.

What are the main factors affecting the analysis of regional economic impacts of alternative jet fuel projects?

Recent analyses of renewable fuels plants suggest that there may be a number of factors affecting the regional economic impact of these facilities. These fall into five categories:

1. **Choice of feedstock:** When analyzing the economic impact of an agricultural processing project, the usual assumption is that the processed commodity is already being produced and, in the absence of the project, is sold to an alternative market. Thus, the direct impacts of the processing operation include payments for locally produced inputs such as labor and utilities but do not include commodity purchases (e.g., plant oil or corn). However, if the feedstock has little or no alternative market (e.g., agricultural residues), sale of these feedstocks to an energy plant represents a new revenue source for farmers and adds to the regional economic impact.
2. **Differences in unit of analysis (county versus state):** Another factor affecting impact analysis studies is differences in the definition of the study area. Some studies estimate impacts for a single county, others for multiple counties, and others for an entire state. None of these approaches is more or less appropriate than another, and the definition of the study area often depends on who constitutes the primary audience—local leaders or state decision makers. However, other things equal, the impacts measured at the state level will always be greater than those for a single county or a multi-county area within the state.
3. **Nature of ownership (local versus corporate):** Another factor that can give rise to substantial differences in impact estimates is the degree of local ownership. If a plant is largely or wholly owned by farmers or other local investors, the profits are distributed to these local owners and

a substantial portion may be spent locally. If the facility is owned by a corporation headquartered elsewhere, the profits leave the local area. In addition, some suggest that some other local expenditures are likely to be greater for a locally owned facility; accounting, administrative, and marketing functions are more likely to be performed locally for a locally owned plant, whereas much of this activity might be centralized off-site for a corporately owned facility.

4. **Specific model/analysis assumptions:** Some differences in impact estimates can result from differences in assumptions incorporated in the impact model and analysis procedure. For example, some analyses incorporate a small premium for locally supplied corn, whereas others do not.
5. **Differences in study areas:** A final factor affecting impact estimates is the nature of the study area. A site area that incorporates a substantial trade center and has a somewhat diversified, self-sufficient economy will have larger secondary impacts, other things equal, than a sparsely populated rural site.

How can the regional economic effects of alternative jet fuel projects be estimated?

The rationale and methods for estimating the economic impact of alternative jet fuel projects are similar to those for assessing impacts of other processing initiatives. The models most often used to measure these types of impacts are input–output, IMPLAN (impact analysis for planning), and RIMS (Regional Input–Output Modeling System). For more information, please refer to *ACRP Synthesis 7: Airport Economic Impact Methods and Models* (Karlsson et al. 2008).

2.6 Possible Economic Implications of Regulation

What are the possible economic implications of regulation on alternative jet fuels?

There are potential economic implications for alternative jet fuel projects that may result from existing and future regulation. It is difficult to determine what the net benefits or disadvantages may be given that many of these rules and regulations are fairly new and lacking details. It is important, however, to be aware of them and to understand that they may have an impact on how the alternative jet fuel industry develops. Listed in the following are some of the more significant regulations with the potential to have economic implications for alternative jet fuel projects.

2.6.1 National Ambient Air Quality Standards

Airport activity is subject to compliance with all federal regulations, including Environmental Protection Agency (EPA) regulations under the Clean Air Act (CAA) (FAA 1997a). The EPA establishes National Ambient Air Quality Standards (NAAQS) for a series of criteria pollutants, including NO_x, SO_2, and PM, which can be present in or result from the exhaust of jet engine emissions. (Such emissions together account for a very small percentage of jet engine emissions.) Geographic areas in which concentrations of these pollutants are determined to be in excess of the NAAQS are designated as non-attainment areas (NAAs) and are subject to formulating a State Implementation Plan (SIP) to bring the area back into compliance (FAA 1997a).

SIPs can affect airports in two important ways. First, an airport in an NAA may be subject to regulation targeted at bringing the area back into compliance with NAAQS. Federal aviation statutes preclude state regulators from imposing emissions requirements on aircraft, but they can affect other non-aircraft sources at the airport, such as on-road vehicles (including cars, taxis, and shuttles), construction equipment, power plants, and other stationary sources. It is not clear if emissions from ground support equipment (GSE) can be regulated by states. Second, if an airport is in an NAA and has plans for a development project, the airport has to show that the project will be in conformity and will not cause or contribute a further violation of an SIP before it can receive federal approval. It is important to note that construction-related

emissions have historically been a significant concern for airports located in non-attainment areas (i.e., subject to SIPs).

Alternative jet fuels may help airports in NAAs meet the goals specified in SIPs because of their potential to have lower emissions levels of criteria pollutants, such as SO_x, NO_x, and PM, as compared to conventional jet fuel. This may allow airports to save time and cost in the approval process for development projects. It may also allow airports to grow their operations without violating existing SIPs.

2.6.2 Emission Reduction Credits

The Clean Air Act of 1990 created an opportunity for industry to buy and sell emission reduction credits (ERCs) tied to atmospheric pollutants (EPA 1990). Airports or airlines operating within an NAA could theoretically generate and sell ERCs if they could demonstrate they are removing criteria pollutants through the supply or use of cleaner aviation alternative jet fuel. As discussed previously, alternative aviation jet fuels can potentially produce less SO_2 and PM than conventional jet fuel, and thus they could potentially generate ERCs. However, while creating a market for ERCs, the Clean Air Act also created restrictions based on New Source Performance Standards (NSPS) in which any entity operating a site subject to NSPS regulations must reduce emissions of criteria pollutants and cannot claim ERCs. Airports interested in claiming ERCs through the introduction of alternative jet fuels should investigate this in more detail.

2.6.3 Domestic and International Policies Related to Greenhouse Gas Reductions

Emissions trading mechanisms have been successfully used in the United States for limiting pollutants and emissions. Examples of successful cap-and-trade programs are the nationwide Acid Rain Program (EPA 2010a) and the regional NO_x Budget Trading Program (EPA 2010d) in the Northeast. In terms of GHG, however, it appears unlikely that the U.S. Congress will introduce a carbon or GHG market system in the near future, even as some states and municipalities have passed rules or legislation that addresses the issues within their jurisdiction. The most notable example is California's Global Warming Solutions Act of 2006, also known as Assembly Bill 32 (AB32), which requires the state to develop regulations to reduce GHG (CAEPA 2009). It is important to note that AB32 does not apply to jet fuel.

Nevertheless, there are developments in other parts of the world that may have an impact on U.S. airports and airlines. For example, the International Civil Aviation Organization (ICAO) is currently analyzing a CO_2 standard for new aircraft. In Europe, EU legislation requires that all airlines landing at EU airports participate in the European Greenhouse Gas Emission Trading Scheme (ETS), a cap-and-trade mechanism that puts a ceiling (cap) on the maximum amount of GHG that airlines can emit (EC 2010). The rules governing the EU's ETS have not been finalized, and its potential economic impact on airlines remains unknown. Several U.S. airlines have taken legal action against this proposed regulation, and as of this date there has been no resolution.

Even though there is still uncertainty with respect to aircraft GHG emissions regulations, the airline industry has been proactive by adopting a common position of a commitment to carbon-neutral growth starting in 2020 (IATA 2009). The industry realizes that alternative jet fuels with a life-cycle GHG footprint smaller than conventional jet fuel can help airlines meet their carbon-neutral growth goals. Furthermore, in the event that GHG emissions targets under the EU's ETS or other potential cap-and-trade mechanisms become mandatory, alternative jet fuels may also help airlines meet their cap and reduce the need to purchase emissions credits. Airports that offer alternative jet fuels could therefore provide benefits to airlines.

2.6.4 EPA Renewable Fuel Standards

The EPA adopted a renewable fuel standard (RFS) called RFS-2 in February 2010 (EPA 2010c). While aviation does not have a required biofuels contribution under RFS-2, producers of alternative fuel for aviation may generate benefits in the form of tradable credits for fuels merited by their ability to provide benefits as quantified by the Renewable Index Number (RIN) of those fuels.

2.6.5 Federal Rules for Purchase of Alternative Fuels

Section 526 of the 2007 Department of Energy (DOE) Authorization mandates that U.S. government buyers can only purchase alternative fuels if their life-cycle GHG footprint is less than that of petroleum-based fuels (Sissine 2007). In the case of alternative jet fuels, this can be of relevance to airports that have or want to attract government customers such as the air national guard.

Furthermore, the U.S. Air Force and DOE have published peer-reviewed procedures to help alternative jet fuel companies verify that their products meet the requirements of Section 526 (NETL 2008; Allen et al. 2009). These documents can also be of value to airports interested in a better understanding of the process to determine the life-cycle GHG footprint of alternative jet fuels and overall compliance with Section 526.

SECTION 3

How Can Alternative Jet Fuels Be Integrated into the Airport Setting?

3.1 Introduction to Evaluation Framework

This section describes a framework for evaluating options to integrate alternative jet fuels into the airport setting. Given that this is a new and developing field, it is likely that many readers will not be as familiar with these kinds of projects and technologies as they are with other common projects at airports. Thus, it is possible that outside experts may have to be engaged to help with parts or the entire framework presented here. Ideally, as the field of alternative jet fuel expands and matures, these projects will become more commonplace and less outside help will be required.

Following are a set of questions to help readers assess their understanding and comfort with the different elements that need to be considered when evaluating alternative jet fuel projects. Answers to these questions provide a means to identify the areas where internal capabilities are sufficient and those where internal capabilities need to be developed or outside expertise may be recommended. The assessment questions can be classified in six categories:

1. **Alternative jet fuel type:** What feedstock and processing technologies can be implemented at my airport?
2. **Safety:** Has the alternative jet fuel been certified for use in aircraft and with existing jet fuel infrastructure?
3. **Environmental goals:** How can the environmental characteristics of the alternative jet fuel be used to help achieve my environmental goals?
4. **Logistics:** How will the alternative jet fuel be delivered to the airport at minimal to no incremental cost? How is the need to provide additional facilities (e.g., storage, blending) being minimized?
5. **Business case:** How can state, federal, and private-sector programs be harvested to evaluate project merits and cost?
6. **Overall evaluation:** Do I have satisfactory answers to the previous questions?

After completing the assessment questions, the reader should evaluate which areas have enough in-house capabilities and which areas would benefit from outside consultation. Once the reader is satisfied that enough expertise is available, the next step is to follow the alternative jet fuel evaluation framework described in the next section. Even if not enough in-house expertise is available, the material in this handbook should provide enough background information to enable the reader to intelligently evaluate the support from outside experts.

3.2 Alternative Jet Fuel Projects Evaluation Framework

The alternative jet fuel projects evaluation framework consists of three steps: (1) understanding who the stakeholders are (Section 3.3), (2) formulating the options and performing an initial screening (Section 3.4), and (3) conducting a comparative evaluation (Section 3.5). Figure 3 illustrates the framework's steps.

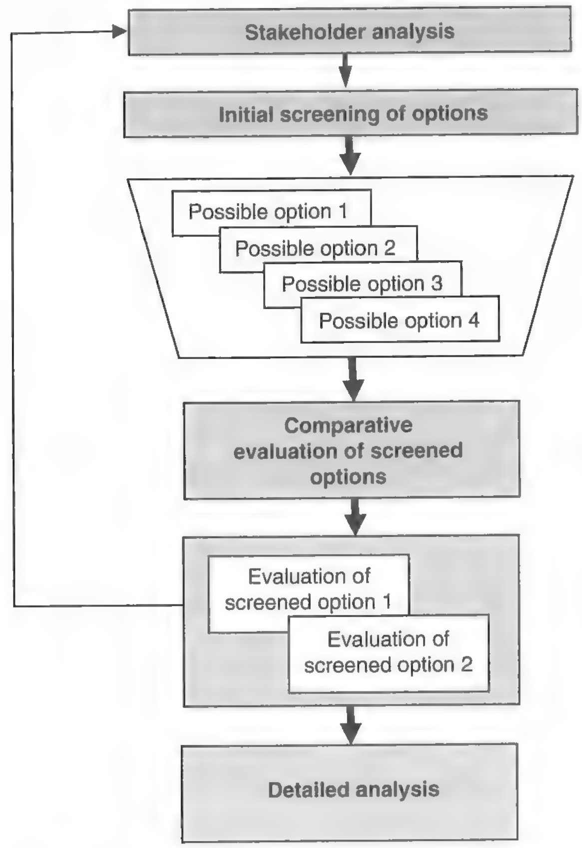

Figure 3. Framework to identify and compare options to bring alternative fuels to airports.

Using the approach in Figure 3 helps the airport understand the needs of relevant stakeholders and apply a series of evaluation criteria to narrow down the multiple options for bringing alternative jet fuel to airports to the most promising few. The result of this process is a few options for a more detailed analysis. This is likely to be an iterative process since there are many factors to consider and the field is evolving rapidly.

3.3 Stakeholder Analysis

Stakeholder analysis is important when evaluating alternative jet fuel projects. An airport that considers engaging in such an effort must have a clear picture of what its customers need before allocating scarce resources. It is also helpful for airports to understand the incentives of other players that may contribute to the success of the project.

Who are the stakeholders likely to be involved in an alternative jet fuel project?

Many stakeholders may become involved in an alternative jet fuel project. Following is a partial list of those expected to play a significant role and whose participation will be required for a successful outcome.

- Feedstock suppliers
- Fuel producers
- Airports

- End users
- Government entities
  - Municipalities
  - States
  - Federal government
- Funding sources
  - Public
  - Private

It is also important to note that alternative fuel projects may not be uniformly supported by all community groups. As discussed in Section 4.1, there are relevant concerns with respect to how alternative jet fuels are produced, in particular if they involve feedstocks that may compete with food or water supplies. Airports must be prepared to address these concerns to ensure opposition does not threaten a good, environmentally beneficial project. Thus, it is recommended that airports proactively engage in (1) communication—provide information about the project and opportunities for the public to meet with airport officials and voice concerns, and (2) preparation—acquire thorough knowledge of the project and its potential impacts and have valid answers for concerns that may be raised.

What do the stakeholders require to participate in an alternative jet fuel project?

Alternative jet fuel projects are more likely to be successful when stakeholders actively support them. Stakeholders have different needs and reasons for participating in an alternative jet fuel project. Following are some typical high-level needs by type of stakeholder.

- **Feedstock suppliers:** higher financial returns than from supplying traditional feedstock to traditional customers; mechanisms to protect financial returns (e.g., crop insurance).
- **Fuel producers:** public-/private-sector financing; long-term supply and offtake contracts that match the terms of the financing arrangements; returns according to the risk of the project.
- **Airports:** no or minimal changes required to existing fueling infrastructure and processes; 100% confidence that alternative fuels are indeed drop-in.
- **End users:** alternative jet fuel cost that is competitive in terms of price with conventional jet fuel; 100% confidence that alternative fuels are indeed drop-in.
- **Government entities (municipalities, states, federal government):** quantifiable and non-quantifiable economic and political benefits.
- **Funding sources (private sector):** expected rates of return according to the risk of the project.
- **Funding sources (public sector):** consistency with the political agenda of the entity; consistency with legislative mandates; best use of limited available funds.

How can the interests and needs of stakeholders be identified?

The interests and needs of stakeholders can be identified and documented using "Worksheet 1: Stakeholder Analysis," in Section 5.2.1. This worksheet provides a detailed template that can be useful to understand the needs of each stakeholder, determine whether or not the project meets those needs, and identify exactly what specific actions must be taken to ensure that the stakeholder actively and energetically supports the project.

3.4 Initial Screening of Options

This step helps the airport make an initial selection of options for producing alternative jet fuels. Given the large number of possible feedstock and technology combinations, it is helpful to isolate a handful of options to consider. The location of the processing facility and the investment's time

horizon provide the best means of focusing the analysis. The options selected through this initial screening can then undergo a more detailed evaluation.

Before starting the initial screening step, it is important for the reader to keep in mind the following two considerations:

1. **Location of the processing plant with respect to the airport:** Local political and land considerations are likely to have a significant impact on the proximity of the processing plant to the airport. For ease of analysis, the proximity options are characterized as follows:
   a. **On-airport:** The processing plant is located within the airport boundary or on airport-owned land.
   b. **Near-airport:** The facility is outside the airport's boundary and jurisdiction but close enough that dedicated transport of the fuel from the processing plant to the airport is economically viable.
   c. **Off-airport:** The plant is sufficiently distant from the airport that fuel must be transported to the airport using the existing transportation infrastructure, such as rail or pipeline, for the project to be economically viable.

The process in this handbook is designed to help airports evaluate the options once the proximity decision is made. Thus, the first decision that airports need to make is to identify where the processing plant is likely to be located. This decision should be based on where sufficient land would be available for the type of facility being considered (see Section 2.3), access to feedstocks, and access to end users. It is likely that the location decision will have to be revised as more information becomes available. If it is not possible to select the location, it is possible to carry out the analysis considering different locations, but the analysis becomes more complex.

2. **Time horizon considerations:** Alternative jet fuel projects have long time horizons. Airports should plan on 4 to 5 years to obtain the permits and design, finance, and build the production facility—once the technology and site have been chosen. The production facility should have an economic life of 10 to 20 years. New alternative jet production technologies are likely to be available every 2 to 3 years; therefore, it is necessary to analyze all existing and potential candidate technologies before committing to one. Help from outside experts is recommended.

The initial screening of options to produce alternative jet fuel is based on two criteria: a feedstock screen and a technology screen, as shown in Figure 4.

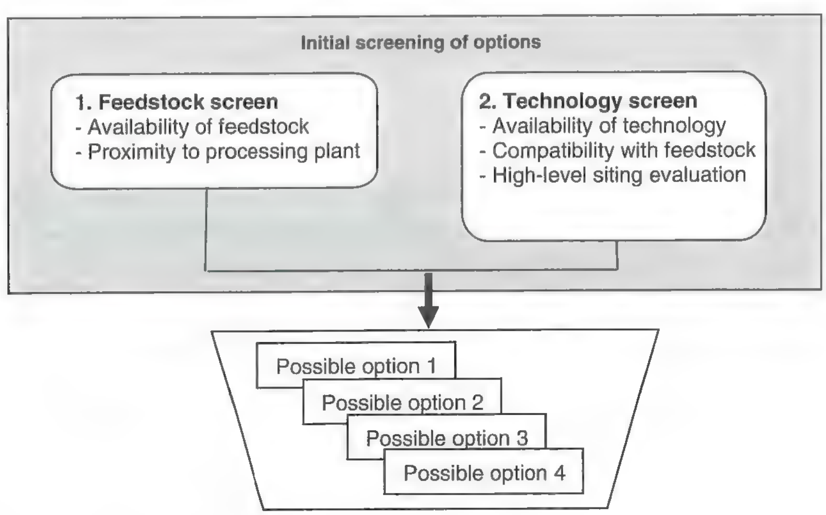

Figure 4. Initial screening of options.

Airports should consider both screens with respect to the possible location of the alternative jet fuel project (on-airport, near-airport, and off-airport). This may be a repetitive process since the location decision and the screens depend on each other. The screening criteria are explained in the following:

- **Feedstock screen**
  - **What feedstocks are available?** Consideration should be given to fossil feedstocks and bio-derived feedstocks. A great deal of work is being done to identify the availability of feedstocks for alternative jet fuel by geographic region. Therefore, it is important to obtain the most recent research. CAAFI is a good resource for the most up-to-date information. Other resources are the National Renewable Energy Lab's interactive Biofuels Atlas (http://maps.nrel.gov/biomass) and the DOE's Bioenergy Knowledge Discovery Network (https://bioenergykdf.net/).
  - **What is the proximity of the feedstock to the processing plant (economics)?** The transport of the feedstock to the processing plant is a key determinant of the cost of the feedstock, and therefore it has a significant influence on the economic viability of the alternative jet fuel. For fossil fuels, plant oils, and animal fats, it is advisable that the processing plant be located close to existing transportation infrastructure such as pipelines, railways, or waterways. For biomass feedstocks, it is widely accepted that the processing plant should be no farther than 50 miles from where the feedstocks are harvested.
- **Technology screen**
  - **What technologies are available?** This screen is highly affected by the time frame. If the airport wants to have a project in operation within 5 years, the technology will likely be limited to FT and hydroprocessing of plant oils or animal fats. If a longer time frame is considered, there are likely to be many options. For the purposes of this handbook, the conversation centers on FT and hydroprocessing since they are the best candidates for near-term implementation.

What technologies are compatible with the feedstocks identified in the feedstock screen? The feedstocks identified in the previous step also determine the technology that can be used. For example, FT can be used with coal, natural gas, or biomass, while hydroprocessing can be used with plant oils or animal fats. CAAFI and the other resources in Section 1.6 should be consulted regarding the latest developments in each of these technologies.

How much area is required to build the plant? A high-level estimate of the land required to build the processing plant is useful at this point. In general, FT plants require a minimum of 10 to 15 acres, while hydroprocessing plants need a minimum of 1 to 5 acres.

At the end of the initial screening, the reader should have identified a number of options to proceed with a comparative evaluation. At this point in the analysis, each option is determined by three elements: (1) location (on-airport, near-airport, off-airport), (2) production technology, and (3) feedstocks.

3.5 Comparative Evaluation of Screened Options

This section evaluates the options identified in the initial screening with respect to four categories: (1) regulatory, (2) environmental, (3) logistical, and (4) financial. This is envisioned to be a simple green/yellow/red rating of each option in each of the four categories that results in a net assessment of each option relative to the others. The purpose of this evaluation is to identify those options that would be ready to undergo a more detailed analysis (see Figure 5).

For each category, the green/yellow/red rating provides guidance regarding how well each alternative fuel option meets the requirements of that category. A green rating means that there

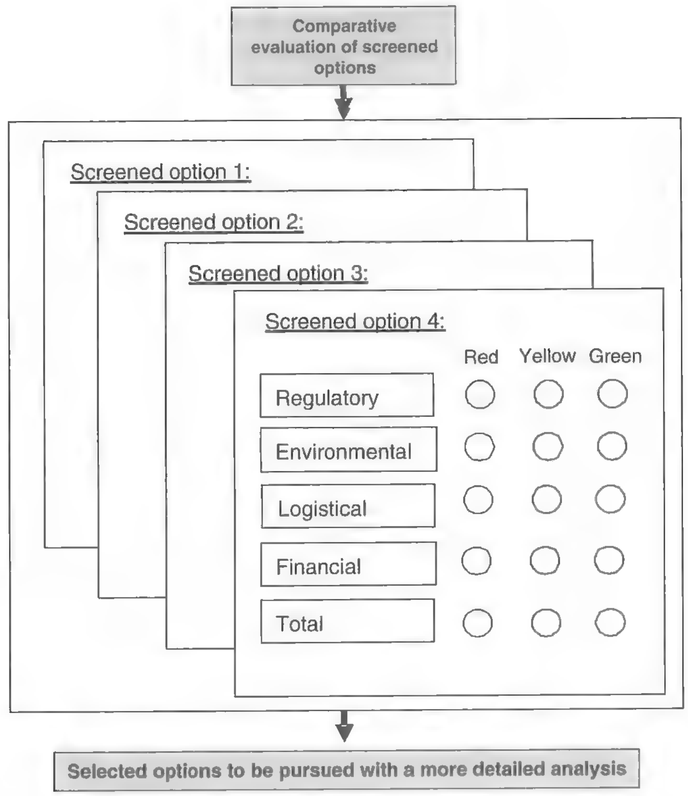

Figure 5. Methodology for comparative evaluation of the screened options.

are no obstacles, yellow means that some obstacles exist that can be remediated, and red means that significant challenges are present and the option needs to be redrawn. Additional detail that can be used to evaluate options against each criterion is discussed in the following sections.

3.5.1 Regulatory

What are the main regulatory elements that should be considered in the evaluation of an alternative jet fuel project?

There are three general regulatory elements that should be considered in the evaluation of an alternative jet fuel project. For each of these elements, this handbook indicates the main questions and associated information that the airport should consider when evaluating alternative jet fuel projects. For more detailed information, please consult the references indicated in the following and in Section 6. In addition, given the complex technical issues surrounding fueling system and airfield design, engaging an aviation consultant engineer familiar with these topics may be advisable to assist with locating a processing facility. The main regulatory elements discussed here are as follows:

- FAA policies and regulations
- Environmental reviews and permitting
- Energy policy

FAA policies: How do FAA policies and regulations affect airport plans to produce and distribute alternative jet fuels?

FAA policies and regulations largely control what can or cannot be done in the airport setting. The construction and operation of alternative jet fuel infrastructure is no exception. The FAA

compiles and maintains a number of documents, including Advisory Circulars (ACs), Orders, and references to other documents that should be considered when evaluating the feasibility of placing alternative jet fuel infrastructure in the airport setting. The FAA and FAA-related documents most likely to be relevant for alternative jet fuel projects are as follows (see Section 6.1 for full citations):

- FAA AC 150/5070-6B, Airport Master Plans
- FAA AC 150/5200-33, Hazardous Wildlife Attractants on or Near Airports
- FAA AC 150/5230-4A, Aircraft Fuel Storage, Handling, and Dispensing on Airports
- FAA AC 150/5300-13, Airport Design
- FAA Order 5050.4B, National Environmental Policy Act (NEPA) Implementing Instructions for Airport Projects
- FAA Order 5190-6b, Appendix R, Airport Compliance Manual
- FAA Order 5190-7, Minimum Standards for Commercial Aeronautical Activities
- FAA Order 1050.1E, CHG 1, Environmental Impacts: Policies and Procedures, Paragraph 304
- Title 14 of the Code of Federal Regulations Part 77, Objections Affecting Navigable Airspace
- Title 14 of the Code of Federal Regulations Part 139, Certification of Airports
- National Fire Protection Association (NFPA) 407, Standard for Aircraft Fuel Servicing
- Best Practices for Environmental Impact Statement (EIS) Management
- *Environmental Desk Reference for Airport Actions*

Together, these documents point to three key items: (1) compliance with all applicable airport design specifications, (2) an evaluation of environmental impacts, and (3) proper documentation of proposed changes. These items are briefly discussed in the following subsections.

In addition to the FAA documents listed previously, it is important to indicate other resources available to jet fuel handlers. For example, the American Transport Association (ATA) publishes ATA Specification 103: Standard for Jet Fuel Quality Control at Airports (ATA 2009c). This document includes recommended specifications that have been developed to provide guidance for safe storage and handling of jet fuel at commercial airports. While these recommendations are not mandatory, they are very closely followed by all major airlines and airports in the United States.

FAA policies: What airport design specifications and standards should be consulted when planning siting and design of an alternative jet fuel processing plant?

Alternative jet fuel processing facilities located on the airport are subject to the same FAA policies and regulations governing any other type of airport facility. In particular, on-airport processing plants and storage facilities must comply with FAA AC 5300-13, Airport Design, which forbids locating fuel storage facilities in the runway protection zones (RPZs). In addition, AC 5300-13 does not allow objects not essential to air navigation or ground maneuvering purposes, such as fuel processing facilities, in the runway object free areas (ROFAs), runway safety area (RSAs), or obstacle free zones. Also of importance is 14 CFR Part 77, Objections Affecting Navigable Airspace, which establishes standards for determining obstructions to air navigation by defining criteria for imaginary surfaces that must not be pierced by any structure, including fuel production and storage facilities. Another consideration is that the proposed project must be shown on the airport layout plan (ALP), as indicated in FAA Order 5190-6b.

Near-airport and off-airport alternative jet fuel processing plants located outside of the airport limits are not subject to the FAA policies and regulations governing on-airport facilities; however, near-airport and off-airport facilities must still comply with 14 CFR Part 77. For example, objects such as light poles, trees, construction cranes, and even tall buildings (sometimes miles away from the airport) can be in violation of 14 CFR Part 77 and would, therefore, present a potential hazard

to aircraft operating in the area. Form 7460-1, Notice of Proposed Construction or Alteration, needs to be completed and filed with the FAA prior to construction for an airspace analysis and determination for either on-airport, near-airport, or off-airport projects.

FAA policies: Are alternative jet fuel projects at airports eligible for Airport Improvement Program funding?

Costs associated with alternative jet fuel production are not Airport Improvement Program (AIP) eligible. Refining and manufacturing of aviation fuels, whether from conventional or alternative feedstocks, are not aeronautical activities. The handling, storing, and delivery of jet fuels to an airplane may be considered aeronautical activity as long as 100% of the fuel is delivered to aircraft on the airport and not distributed elsewhere. Therefore, on-airport fuel storage is eligible but only using non-primary airport entitlements. Furthermore, since the production of alternative fuels is not an aeronautical activity, leases will need to be at fair market value.

For more information, airports are encouraged to contact their local FAA office. Contact information for FAA regional offices is available at http://www.faa.gov/about/office_org/headquarters_offices/arp/regional_offices/.

FAA policies: What items must be considered to ensure compatible planning with existing and future surroundings?

Being a good neighbor is often a principle that airports adopt since it can enable a mutually beneficial relationship between airport operators and surrounding developments and avoids potentially costly litigation. In order to avoid conflict with airport surroundings, land-use zoning must be done carefully in the areas near an airport.

In general, zoning rules and regulations vary considerably from one jurisdiction to another and it is not practical to summarize them in this document. Airports should consult *ACRP Report 27: Enhancing Airport Land Use Compatibility* (Ward et al. 2010) for a deeper discussion of this topic. Nevertheless, there are a few general observations that can help airports evaluate alternative fuel projects with respect to zoning:

- **Obstacles to air navigation:** The FAA requires that there be no object, man-made or natural outgrowth, 200 ft from the ground level of the airport and within a 3-nautical-mile radius of the established reference point of the airport. Other requirements are listed in Federal Aviation Regulations (FAR) Part 77.
- **Noise assessment:** If construction of alternative jet fuel facilities requires modifications to existing airspace procedures, the FAA and airport would need to comply with NEPA requirements. This may require a proper environmental impact statement (EIS) before the FAA can approve route changes when there is a significant noise impact on the affected population. Noise impacts from the alternative jet fuel facility on the immediate surroundings should also be investigated for potential permitting review requirements.
- **Agricultural land near airports:** The FAA recommends against using airport property for agricultural production because agricultural crops can attract wildlife (FAA 1997b). If the airport requires agricultural crops as a means to produce income necessary for the viability of the airport, it needs to follow the crop distance guidelines established in AC 150/5300-13, Appendix 17. Airports should be advised that the FAA may require a wildlife hazard assessment (WHA) or a wildlife hazard management plan (WHMP) when specific triggering events occur on or near an airport, as specified in 14 CFR Part 139, Certification of Airports. Such events include an aircraft striking wildlife, an aircraft engine ingesting wildlife, or observing wildlife of a size or in numbers capable of causing an aircraft strike or engine ingestion. The WHA plan must be conducted by biologists with appropriate training and education as spec-

ified in AC 150/5200-36. Agricultural land use is compatible with airport operations from a noise sensitivity perspective (FAA 2001).

Environmental reviews: What environmental review requirements should be considered?

Jurisdictions at the federal, state, and local levels require permits for those activities or facilities they view as affecting the environment, safety, or equity of the surrounding population. Alternative jet fuel plants affect each of these three components. In general terms, the main categories of interest in the environmental review and permitting process tend to be the following:

- Water quality, including environmental impact on drinking water, groundwater, wastewater, and surface waters, including storm water, coastal areas, wetlands, and floodplains.
- Air quality, including environmental impact of gaseous and other emissions.
- Impacts to endangered species or historic, coastal, or other environmental resources by facility construction, operation, maintenance, or access.
- Land quality, including solid waste disposal, hazardous waste handling and disposal, and spill prevention, reporting, and cleanup.
- Land-use planning and zoning, including impacts to shared infrastructure such as roads and railways.

Environmental reviews: What guidance is there to meet the environmental permitting requirements?

At the federal level, alternative jet fuel projects need to comply with NEPA and applicable laws protecting sensitive environmental resources. NEPA outlines a process by which agencies are required to determine if their proposed actions have significant environmental effects. Depending on the severity of the environmental effects, a categorical exclusion (CE), environmental assessment (EA), or EIS may be required (see FAA Order 1050.1E for more information). In particular, the environmental issues addressed in the *Environmental Desk Reference for Airport Actions* (FAA 2007) or Appendix A of Order 1050.1E should be investigated during the NEPA process. This must occur before the FAA can make a decision on approving an alternative jet fuel facility.

For alternative jet fuel projects on the airport, airports should refer to FAA Order 1050.1E, which is the FAA's umbrella guidance for NEPA compliance. Installation of on-airport fuel facilities requires the FAA to issue an unconditional approval to an airport layout plan. This requires the FAA to complete its environmental analyses under NEPA and other laws, such as special purpose laws, protecting sensitive species (see the *Desk Reference for Airport Actions* for more information). Other actions of the FAA that may be applicable to alternative jet fuel production include federal funding and release of federal lands.

Additional reviews related to Clean Air Act statutory programs, such as New Source Review and New Source Performance Standards, may be required. These address construction permits or installation of emission control technologies for new facilities or modification of existing major sources that might result from locating an alternative jet fuel facility at or near an airport. Note that these reviews are not limited to non-attainment areas. A Clean Water Act permit may also be required.

At the state and local level, there is a high degree of variation in terms of environmental review and permitting requirements and regulations. They often vary from one jurisdiction to the next. Many states are developing review processes and integrated guidance materials on environmental review and permitting activities relative to infrastructure that may be applicable to alternative jet fuel projects (see Section 6.2). Furthermore, the EPA maintains a database of state-specific regulatory information at http://www.epa.gov/lawsregs/states/index.html#state.

How can the FAA's regulatory and environmental review considerations of an alternative jet fuel project be evaluated?

To evaluate the regulatory aspects of an alternative jet fuel project, use "Worksheet 2: Regulatory Considerations," provided in Section 5.2.2. The following evaluation guide is recommended for grading the different options after Table 9 in the worksheet has been completed:

- Green: The project can meet all regulations and other considerations. (Only boxes in "Meets Regulation/Consideration" column are checked.)
- Yellow: The project is likely to meet all regulations and other considerations with some extra effort. (Most boxes in "Meets Regulation/Consideration" column and only a few in "Likely to Meet Regulation/Consideration" column are checked.)
- Red: The project cannot meet all regulatory and other considerations. (One or more boxes in "Does Not Meet Regulation/Consideration" column are checked.)

After completing the grading, fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "FAA regulations and environmental review" row of "Worksheet 6: Evaluation Summary" in Section 5.2.6.

Energy policy: What governmental and nongovernmental entities have stated their support for alternative jet fuel projects?

Support for alternative jet fuel projects comes from various entities and policies, including the federal government and nongovernmental organizations (NGOs). This section summarizes some of the most visible entities and policies and indicates how they may be helpful to alternative jet fuel projects:

- **The current administration in the White House:** The White House has a policy framework that supports both biofuel production and the allocation of funds to aviation fuel sources. These policies include a commitment made in 2009 by the USDA to allocate funds to biofuels development (USDA 2009) and the 2010 Biofuels Interagency Working Group report highlighting aviation fuel deployment. This report calls for using pre-established market outlets and customer purchase commitments to stimulate production of feedstocks and biofuels (EPA 2010e). These policy support statements culminated in August 2011 with a White House initiative that provides a $510 million, 3-year commitment by the Navy, USDA, and DOE of multiple alternative fuel projects (The White House 2011). White House policy statements are of significance to airports since they can help airport leadership establish priorities and identify agencies tasked by the White House to implement alternative fuel support programs.
- **FAA:** The FAA Office of Environment and Energy sets policy and offers programs to monetize the benefits of using alternative fuels. Relevant initiatives sponsored by this office include:

  NextGen Environmental Working Group: This group, part of the Joint Program Development Office (JPDO), sets goals for carbon and particle emission reductions associated with aviation traffic growth projections enabled by NextGen. One important use of alternative fuels is to offset carbon growth associated with this traffic growth.

  Partnership for Air Transportation Noise and Emission Reduction (PARTNER) Project 20—Emissions Characteristics of Alternative Aviation Fuels: This project characterizes particle emission measurements for a series of alternative fuels (PARTNER 2010a). Airports can use Project 20's measured outcomes to establish actual particle outcomes for specific process outputs under consideration.

  PARTNER Project 27—Environmental Cost-Benefit Analysis of Ultra Low Sulfur Jet Fuels: This project established the health effects of particles for use in conjunction with the FAA's Aviation Portfolio Management Tool (APMT) suite (PARTNER 2010b). While not an alternative fuel in itself, low-sulfur versions of conventional jet fuel are currently under evaluation by FAA as a possible complement to alternative fuel options to contain sulfur and related particle costs.

PARTNER Project 28—Environmental Cost-Benefit Analysis of Alternative Jet Fuels: This project quantifies aviation-specific GHG emission levels for a range of alternative fuel options that may be proposed for adoption by airports and their stakeholders (PARTNER 2010c). Airports can use these results in conjunction with Section 2.4 to establish the actual GHG benefits for specific feedstocks and processes.

The FAA has other programs that may be of interest for alternative aviation fuel projects. These include:

Voluntary Airport Low Emissions (VALE) Program: VALE was established in 2004 to help commercial service airports in designated air-quality non-attainment and maintenance areas reduce airport ground emissions (FAA 2011b). VALE allows airport sponsors to use the AIP and passenger facility charges (PFCs) to finance low-emission vehicles and certain infrastructure projects. However, projects that use alternative jet fuels are not eligible for funding under VALE. Participation in the program could still be valuable for airport sponsors as a means to gain valuable experience structuring projects that reduce air emissions using other clean-energy fuels.

Sustainable Master Plan Pilot Program: This program was recently introduced by the FAA and is evaluating ways to make sustainability a core objective at every airport (FAA 2011a). It is funding long-range planning documents at 10 airports around the country. These documents, called Sustainable Master Plans and Sustainable Management Plans, will include initiatives for reducing environmental impacts, achieving economic benefits, and increasing airport integration with local communities. The program is projected to end in late 2012. This program may provide valuable information to airports interested in integrating alternative jet fuel projects into their sustainability initiatives.

- **Public/private partnerships and coalitions:** Several organizations focused on the development and deployment of alternative jet fuels have been formed over the past few years. These include:

Commercial Aviation Alternative Fuels Initiative: CAAFI is a coalition of government and private-sector organizations, including the FAA Office of Environment and Energy; Aerospace Industry Association (AIA), representing manufacturers; ATA, representing airlines; and Airport Council International–North America (ACI–NA), representing airports (CAAFI 2010). CAAFI's 350 members represent nearly 250 separate entities, including some 17 U.S. government agencies.

CAAFI may be contacted through its public website, www.caafi.org. Airport personnel can also join CAAFI for no membership charge and gain access to all documentation and guidance on its password-protected site.

ATA/Defense Logistics Agency Alliance: In March 2010, the ATA signed an agreement with the Defense Logistics Agency (DLA, formerly the Defense Energy Support Center or DESC) to pursue joint policies for the purchase of alternative fuels. The alliance seeks to align purchasing policies, promote deployment, and pursue common economic policies (ATA 2010b). The alliance covers over 90% of all jet fuel purchased in the United States. It maintains teams on deployment, contracting, and the environment, and will work with potential project developers to establish means of best accessing those markets.

Farm to Fly: The Farm to Fly coalition of interest between U.S. Department of Agriculture, the ATA, and Boeing was formed in July 2010 (ATA 2010a). The coalition brings together agriculture, energy, and aviation interests to support deployment activity, initially working on bottom-up models for developing fuel supplies for aviation regions of the United States.

Other regional coalitions: There are regional initiatives focused on partnerships for the development of alternative fuel projects in specific geographic areas. Examples include the Georgia Center of Innovation for Energy (GCI 2011), the Hawaii Renewable Energy Alliance (HREA 2011), Clean Fuels Ohio (CFO 2011), and the Sustainable Aviation Fuels

Northwest (SAFN) in the U.S. Pacific Northwest region (SAFNW 2011a). SAFN just published a detailed report analyzing and evaluating the potential for alternative jet fuel production in their region (SAFNW 2011b).

- **Aviation-related nongovernmental organizations:** The entities listed in the following may help airports in the development and evaluation of alternative jet fuel projects by sharing best practices, case studies, and other expertise.

  International Air Transport Association and its stated industry goal of carbon neutral growth by 2020 (IATA 2010).
  Air Transport Association and its policy on alternative fuels (ATA 2010c).
  Airport Council International–North America (ACI–NA) and its sustainability and business policies (ACI–NA 2010).
  Sustainable Aviation Fuel Users Group and its policies (SAFUG 2011).
  Non-aviation-related nongovernmental organizations: There are nongovernmental organizations not directly associated with aviation that have participated in alternative jet fuel forums and are aware of the development of alternative jet fuel. Even though their policies are not necessarily focused exclusively on aviation alternative fuels, they offer different perspectives that may be important to consider when evaluating projects. These entities include:

  Roundtable on Sustainable Biofuels (RSB) and its best practices (RSB 2010).
  Environmental NGOs: Several environmental NGOs, such as the National Resources Defense Council and the World Wildlife Federation, have participated in alternative jet fuel forums at the request of CAAFI in the United States and the Sustainable Way for Alternative Fuel and Energy in Aviation (SWAFEA) in Europe.

Energy policy: What programs exist to fund studies and other nonrecurring investments in alternative jet fuels?

Readers should consult with CAAFI to determine which of the programs presented in the following can be useful to identify and support potential alternative jet fuel projects at their facilities. The following programs may exist at the federal, state, or local levels:

- **Biomass Crop Assistance Program (BCAP)** associated with the 2008 USDA Budget Authorization section 9000 for renewable energy (USDA 2010c).
- **Value-added grants and state enterprise grants** for rural renewable energy project evaluation and development (USDA 2010p, USDA 2010m). The execution of this type of projects needs to be submitted for funding in many cases through agricultural institutions. One example of this process is afforded by a proposal made via the Soy Bean Growers Association in Ohio (OHSOY 2010) for a brownfield plant conversion to produce alternative jet fuel.
- **Military Title III programs** that can enable initial plant construction for national defense priorities (Finnessy 2006).
- **The August 2011 three agency announcement** to support the development of advanced biofuels is supported by a $510 million commitment (The White House 2011). The rules concerning how these funds will be used have not been finalized as of October 2011, but it is expected that this program will be an important source of funding for alternative aviation fuel projects over the next 3 years.

Energy policy: What programs exist that may allow recurring support for alternative jet fuel projects?

The following policies may take a variety of forms, including tax incentives, insurance for crops, and tax credits for alternative jet fuels. The details of these policies may still have to be refined, so airports are encouraged to contact CAAFI for guidance. These programs may exist at the federal, state, or local levels:

- **Federal and state government programs:** The federal government and many states offer incentives for the development of alternative fuels. The Department of Commerce keeps a list of those programs that could apply to alternative jet fuel or avgas projects (DOC 2011). The Department of Energy maintains a full list of incentives for all sorts of alternative fuel programs as well as a map of existing demonstrator programs (DOE 2011b). The final rules for implementing the August 2011 three-agency initiative should be consulted. These rules are expected to specify how co-investments in projects by other public- and private-sector entities will be evaluated, making these rules particularly important.
- **Possible price supports** for growers and price collars for buyers and sellers, similar to those available for food crops (USDA 2010a).
- **Department of Defense (DOD) policies** involving alternative fuel commitments such as the plan to have 50% of continental U.S. military jet fuel consumption sourced from synthetic fuels blends (Andrews 2009).
- **Tax credits** such as the one-dollar-per-gallon tax credit for biofuels (currently renewed on a year-by-year basis) (American Fuels 2010).

Energy policy: How can the energy policy elements of an alternative jet fuel project be evaluated?

"Worksheet 3: Energy Policy Considerations" in Section 5.2.3 can be used to evaluate energy policy elements and corresponding sources of support. After checking the appropriate boxes in the worksheet, the following evaluation guide is recommended for grading the different options:

- Green: All or most policies are applicable. (Most or all boxes checked are in the "Applicable" column.)
- Yellow: Some policies are applicable and most may be applicable. (Some boxes checked are in the "Applicable" column, most boxes checked are in "May Be Applicable" column, and some boxes checked are in "Not Applicable" column.)
- Red: No policies are applicable. (Most boxes checked are in "Not Applicable" column.)

After completing the grading, fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "Energy policy" row of "Worksheet 6: Evaluation Summary" in Section 5.2.6.

Note: This evaluation is intended to reflect the possible strength of support from a number of entities and their policies on alternative jet fuels for individual project options. A grading of red does not mean that a project is not viable. Such a grading would only indicate that the project does not appear to benefit from the potential support of the entities listed in the worksheet. This may put a given project at a disadvantage compared to other projects that may get a higher grade in energy policy considerations.

3.5.2 Environmental

As discussed in Section 2.4, alternative jet fuels have two principal potential environmental benefits. First, the overall life-cycle GHG footprint may be lower than for conventional fuel. Second, particulate emissions such as $PM_{2.5}$ may be lower. Reductions in NO_x have been documented for alternative ground fuels (relative to diesel fuel), but there is no current evidence to suggest that the same benefit extends to alternative jet fuels. Information on how to evaluate the GHG and particulate matter benefits of alternative jet fuel options is presented in the following.

How should the life-cycle GHG footprint of alternative jet fuels be determined?

As discussed in Sections 2.4 and E.1, the life-cycle GHG footprint of alternative jet fuels should be determined with a suitable LCA methodology. To date, there is no one methodology that is universally accepted; however, materials produced by the Department of Defense (Allen et al. 2009) and PARTNER (Stratton, Wong, and Hileman 2010) offer sufficient guidance and are

recommended for a first-order analysis. Consultation with outside experts is recommended for a more in-depth study.

In terms of targets for desired life-cycle GHG footprints of alternative jet fuels, the airport should be aware of the needs of potential users and set reasonable expectations. The development of alternative jet fuel will be incremental. As technologies develop and feedstocks mature, it is expected that the life-cycle GHG footprint of these fuels will improve. Thus, supporting production of alternative jet fuels that achieve even only modest reductions in the near term is important to spur development of fuels achieving larger reductions in the future.

What questions should be considered in this part of the evaluation?

Questions that should be considered in this part of the evaluation are as follows:

1. What is the estimated life-cycle GHG footprint of the alternative jet fuels being considered in the option?
2. What is the overall net footprint of the blend of alternative jet fuel and conventional fuel, given that alternative jet fuels have only been certified as blends?
3. What is the range of uncertainty in the answers to (1) and (2)?

These questions should be answered with the latest available official estimates of life-cycle GHG footprints. As mentioned previously, it is recommended that outside experts be engaged to conduct this analysis since there is still no one methodology that is universally accepted. A sample calculation is as follows:

Alternative fuel: Coal and switchgrass to FT fuel, with CCS

Estimated life-cycle GHG footprint: 53.0–56.9 g CO_2e/MJ, relative to 87.5 g CO_2e/MJ for conventional petroleum-based jet fuel (data from Table 4 in Section 5.1). (Where g CO_2e is grams CO_2 equivalent; MJ is megajoules.)

Estimated mix of alternative and conventional fuels: 50/50

Resulting overall footprint of fuel mix, relative to 100% conventional case:

$$\text{relative footprint (low)} = [(0.5 \times 53.0) + (0.5 \times 87.5)] / (1.0 \times 87.5) = 70.25 / 87.5 = 0.80$$

$$\text{relative footprint (high)} = [(0.5 \times 56.9) + (0.5 \times 87.5)] / (1.0 \times 87.5) = 72.20 / 87.5 = 0.83$$

Thus, the proposed alternative fuel at the proposed level of mixture with conventional jet fuel is estimated to reduce the overall life-cycle GHG footprint of the fuel being used by between 17% and 20%.

How can the life-cycle GHG footprint of alternative jet fuels be evaluated?

The net environmental evaluation of the relative life-cycle GHG effects may be done using the following rating:

- Green—Use this rating if the alternative jet fuel is likely to achieve life-cycle GHG reductions.
- Yellow—Use this rating if the alternative jet fuel may achieve life-cycle GHG reductions.
- Red—Use this rating if the alternative jet fuel is not likely to achieve life-cycle GHG reductions.

After completing the grading, fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "Life-cycle GHG" row of "Worksheet 6: Evaluation Summary" in Section 5.2.6.

How should the local air quality benefits of alternative jet fuels be determined?

As with life-cycle GHG, outside experts should be consulted to perform a detailed calculation of $PM_{2.5}$ benefits. A simple methodology is presented in the following to perform a first-order approximation estimate.

In terms of targets for $PM_{2.5}$ emission reductions, the focus should be that any reduction because of the introduction of alternative jet fuels is beneficial. This is especially true if the airport is in a NAAQS non-attainment zone, although the benefits are important even if the airport is not in a non-attainment zone.

What questions should be considered in this part of the evaluation?

Questions to be considered in this part of the evaluation are:

1. What is the estimated reduction in $PM_{2.5}$ emissions of the alternative jet fuels being considered in the option?
2. What is the overall $PM_{2.5}$ intensity of the resulting mix of fuels at the airport, considering the expected percentage of total fuel that will be provided by the alternative fuel?
3. What is the range of uncertainty in the answer to (2)?

These questions should be answered with the latest available official estimates of $PM_{2.5}$ intensity. A sample calculation is as follows:

Alternative fuel: coal and switchgrass to FT fuel, with GHG capture

Estimated $PM_{2.5}$ intensity: 0.25–0.5, relative to 1.0 conventional petroleum-based jet fuel (data from Figure 7 in section 5.1).

Estimated mix of alternative and conventional fuels: 50/50

Resulting overall $PM_{2.5}$ intensity of fuel mix, relative to 100% conventional case:

$$\text{relative footprint (low)} = [(0.5 \times 0.25) + (0.5 \times 1.0)] \,/\, (1.0 \times 1.0) = 0.63$$

$$\text{relative footprint (high)} = [(0.5 \times 0.5) + (0.5 \times 1.0)] \,/\, (1.0 \times 1.0) = 0.75$$

Thus, the proposed alternative fuel at the proposed level of mixture with conventional jet fuel is estimated to reduce the overall $PM_{2.5}$ intensity of the fuel being used by between 25% and 37%.

How can local air quality benefits of alternative jet fuels be evaluated?

Net environmental evaluation of the relative $PM_{2.5}$ intensity effects may be done as follows:

- Green—Use this rating if the alternative jet fuel is likely to achieve $PM_{2.5}$ emissions reductions.
- Yellow—Use this rating if the alternative jet fuel may achieve $PM_{2.5}$ emissions reductions.
- Red—Use this rating if the alternative jet fuel is not likely to achieve $PM_{2.5}$ emissions reductions.

After completing the grading, fill in the appropriate circle in the "Green," "Yellow," or "Red" column of "Worksheet 6: Evaluation Summary" in Section 5.2.6.

3.5.3 Logistical

This section provides guidance regarding the evaluation of the main logistical elements for an alternative jet fuel project.

What are the main logistical elements that should be considered in the evaluation of an alternative jet fuel project?

There are two main logistical elements that should be considered in the evaluation of alternative jet fuel projects: (1) the transportation and storage of feedstocks and (2) the transportation and storage of the alternative jet fuel. A simplified diagram of the supply chain of alternative jet fuels from feedstock extraction to the airport is shown in Figure 6.

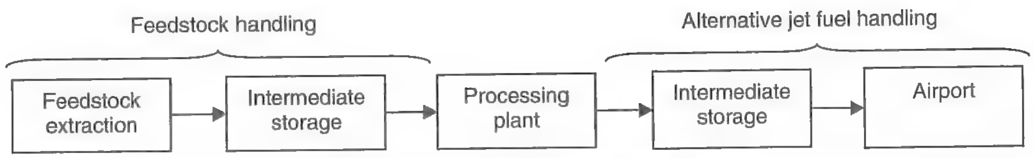

Figure 6. Schematic of the alternative jet fuel supply chain.

What are the options for transporting feedstocks to the processing plant?

The options for transporting feedstocks to the processing plant depend to a large extent on the type of feedstock. The main options are:

- **Coal and natural gas:** Coal is typically transported by rail, and natural gas is normally shipped by pipeline. Both transportation modes are well developed in the United States and offer the most cost-efficient ways for bulk transportation. However, given that building new rail lines or pipelines is very expensive, alternative jet fuel projects should be located close to existing infrastructure. More information on existing rail and pipeline infrastructure is available at the National Atlas of the United States (http://www.nationalatlas.gov/natlas/Natlasstart.asp) and the U.S. Department of Transportation's National Pipeline Mapping System (http://www.npms.phmsa.dot.gov/), respectively.
- **Plant oils:** For traditional plant oils such as soybean and canola, existing transportation and logistics infrastructure can be used; however, similar to the case of coal and natural gas, the processing facility would have to be located within reach of the existing infrastructure to enjoy full benefits. For new types of plant oils, such as *Camelina*, it is possible that the existing transportation and logistics infrastructure may be used. If this is the case, the transportation of these plant oils would be much more economical than if new infrastructure were built.
- **Dedicated energy crops and other biomass:** These materials are typically transported by truck; however, since they are bulky and not very dense, economics limit their transportation to a distance of about 50 miles from the processing facilities.

For these feedstocks, intermediate storage may be required depending on the particular organization of the supply chain. For example, the harvest of energy crops is seasonal and the timing of the harvest may vary depending on crop and region of the country; however, processing facilities need feedstock year round to maximize utilization. Therefore, if biomass were used as a feedstock, storage at an intermediate location or at the processing facility should be considered.

What are other logistical elements associated with agricultural feedstocks that need to be considered?

In the case of agricultural feedstocks, an important element in the supply chain is a supply contract. Since the most common situation will be of one buyer and many suppliers, a single entity may be required to contract with many producers for a biomass.

What are the options for transporting alternative jet fuel to the airport?

The main options for transporting alternative jet fuel to the airport are:

- **Pipeline:** This is the most cost-effective option for transporting the finished fuel, especially if the processing plant and the airport already have pipeline access.
- **Rail or barge:** Rail or barges are the next most cost-effective options for transporting finished fuel. As in the case of pipelines, the maximum benefit is achieved if both the processing plant and the airport already have access to rail or barges.
- **Truck:** This is the least cost-effective option for transporting the finished fuel; however, truck transportation provides the most flexibility because it does not require the existence of expen-

sive infrastructure such as pipelines or railways. Thus, in the absence of pipelines or railways, truck transportation may be the most practical option.

What are the logistical implications of the blending requirement of alternative jet fuels?

Since thus far alternative jet fuels have only been certified as a blend (up to 50% in the case of FT), there will have to be a place in the supply chain, prior to the fuel reaching the wing of the aircraft, where alternative and petroleum-based jet fuels are blended. This is not expected to be a considerable barrier for an alternative jet fuel project, but it needs to be considered.

Can alternative jet fuels use the same infrastructure as conventional jet fuel?

As long as the alternative jet fuel is certified as a drop-in fuel, it can use the same infrastructure as conventional jet fuel. If the alternative jet fuel is certified as a blend (e.g., 50/50 blend), only the infrastructure downstream of the blending facility could be shared with conventional jet fuel. It is important to point out that infrastructure is a shared resource serving many customers. Therefore, all users who use that infrastructure must agree to the alternative jet fuel being present.

How can the logistical characteristics of an alternative jet fuel project be evaluated?

To evaluate the logistical aspects of an alternative jet fuel project, "Worksheet 4: Logistical Considerations" is provided in Section 5.2.4. Fill out the information for the current way in which the airport gets its conventional jet fuel and for as many options as are being considered. The following evaluation guide is recommended for grading the different options:

- Green: All or most transportation occurs by pipeline or rail/barge with minimal or no truck transportation; all transportation and storage infrastructure is in place.
- Yellow: Some truck transportation is required. Some minor transportation and storage infrastructure needs to be built.
- Red: Truck transportation over long distances is required. Major transportation and storage infrastructure elements need to be built.

After completing the grading, fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "Logistical" row of "Worksheet 6: Evaluation Summary" in Section 5.2.6.

Note: It is important to compare the proposed options to the existing way of bringing jet fuel to the airport. For example, a yellow rating is appropriate if truck transportation is the only possibility for both the alternative jet fuel and the petroleum-based jet fuel.

3.5.4 Financial

Financial resources are another critical element for a successful alternative jet fuel project. This section discusses the main financial considerations that should be taken into account.

What are the main financial considerations related to alternative jet fuel projects?

Commercial-scale alternative jet fuel plants are large, capital-intensive projects that are very likely to require external financing. Alternative jet fuel facilities frequently involve more financial risks than the average airport project because the technologies are new and frequently untested on a commercial scale. As a result, alternative jet fuel projects may have more difficulty in attracting financing than most airport projects. Thus, in order to attract financing, project developers must be able to demonstrate a high probability of the operation being profitable. This usually means that the technology has been proven on a commercial scale and that an independent feasibility study analyzing the likelihood of success of the project is available. Such a feasibility study will ultimately require hiring an outside expert and is outside of the scope of this handbook; however, there are some initial considerations, discussed in the following, that airports can analyze prior to deciding on a full-scale feasibility study.

The success of an alternative jet fuel project depends heavily on one external factor: the price of conventional jet fuel. Airlines and other end users may be willing to pay a premium for alternative jet fuel during a short start-up period, but eventually they will expect the alternative jet fuel to compete with conventional jet fuel in terms of price. At the moment, many indications are that the price of alternative jet fuel will be initially higher than that of conventional jet fuel. As the industry grows and matures, the price of alternative jet fuel is expected to decrease. When and how fast this happens, and how quickly profitable business models emerge, will be important for the financial success of alternative jet fuel projects.

What financial elements should be evaluated as part of a comparative evaluation of options?

"Worksheet 5: Financial Considerations" in Section 5.2.5 and the text following this paragraph offer a road map for airports to perform a comparative financial evaluation of alternative jet fuel projects. For each option under consideration, start with the first step and follow the decision tree providing answers to the questions. A guide to rate each option based on these answers is provided. This worksheet represents an iterative process. If a rating of red or yellow is obtained, repeat the exercise taking into account new or expanded information that may be obtained through consultation with CAAFI and other experts such as those listed in Section 1.6.

1. Does the project have a financing structure in place?

If the project already has a firm financing commitment, the project is likely to be financially feasible because the financial institution will have completed its own feasibility review. If so, the project gets a green rating.

If firm financing commitments are not available, continue with Step 2. For each of the following questions, answer "Yes" or "No" in Worksheet 5.

2. Has the proposed technology and feedstock been used before?

The use of an untested technology or feedstock for producing alternative jet fuels increases the risk of the project. To get a better idea of the risk factors, financial institutions would want to investigate the following:

a. Has the proposed alternative jet fuel been certified for use in aircraft?
b. Has the production technology been proven at the same scale as this project?
c. Have the feedstock and alternative jet fuel logistics been solved?
d. Are the feedstocks available in adequate supplies and at prices that make the alternative jet fuel competitive over the life of the project?
e. Does the alternative jet fuel project have a long-term supply agreement with sufficient disruption and quality protections?
f. Does the alternative jet fuel project have long-term purchase agreements from creditworthy buyers?

CAAFI and the resources listed in Section 1.6 can be consulted to help find the answers to these questions.

3. Are there indications that the production process can be profitable?

Airports should determine if similar ventures to the one being evaluated are profitable (note that a nondisclosure agreement may have to be signed to obtain this information).

4. Does the project sponsor have a successful track record?

Financing sources need to be confident that management of the fuel production facility is competent and will be capable of carrying out the business plan. Management with a successful track record is more likely to attract financing than untested management.

5. Does the business plan show a profit under most scenarios?

The business plan should demonstrate the effect that changes in feedstock costs or conventional jet fuel costs will have on the profitability of the operation. Airports should question what types of alternative jet fuel purchase agreements the operation has in place and ask whether the operation will be profitable if a major customer does not honor its agreement and the alternative jet fuel must be sold on the spot market.

6. Is there a creditworthy entity that will guarantee financing?

For projects that might not otherwise meet all the requirements needed to obtain private-sector financing, the government may be able to step in to bridge the gap between the project's actual and required equity and debt returns. Lenders are generally more risk averse than equity providers and need to be confident that the loan will be repaid under the most adverse circumstances. With new industries, this may involve obtaining a loan guarantee that ensures debt repayment if the alternative jet fuel venture fails. Developers will likely seek debt guarantees from a range of federal, state, and municipal agencies. Airport management should have a plan for how it will respond if such a request is made.

After completing the grading, fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "Financial" row of "Worksheet 6: Evaluation Summary."

3.5.5 Overall Evaluation and Selection of Options for Further Study

After the regulatory, environmental, logistical, and financial considerations for a particular option have been evaluated, "Worksheet 6: Evaluation Summary" in Section 5.2.6 should have the consolidated results from the individual worksheets. Once all alternative jet fuel options under consideration have been evaluated, they can be compared against each other to select the ones that should undergo a more detailed analysis. Ideally, there will be options with ratings of just green or green/yellow. These are candidates for further study. Options with a red rating should be redrawn and modified until their evaluation results in only green or yellow ratings.

3.6 Suggested Next Steps

Those options that ranked green or yellow as described in Section 3.5.5 advance to the next step of a more detailed evaluation. Such an evaluation should entail some or all of the following steps:

- Thorough analysis of the regulatory aspects, including detailed descriptions of how the option complies with each applicable regulation and policy.
- Thorough analysis of the environmental aspects, including assessment of life-cycle GHG intensity as provided by the responsible external agency (e.g., EPA), or as developed following procedures provided by that agency. Similar analysis applies to environmental benefits associated with particulate matter.
- Thorough analysis of the logistical aspects, including an end-to-end engineering plan quantitatively addressing each stage in the processing, movement, and storage of the alternative jet fuel.
- Thorough analysis of the financial aspects, including an investment-quality business plan that specifies capitalization, revenue, costs, and risks at appropriate intervals over the lifetime of the enterprise.

SECTION 4

Frequently Asked Questions

4.1 What Are Some of the Potential Community Concerns About Alternative Jet Fuel?

Q: What is the "food-versus-fuel" debate and how does it relate to alternative jet fuel?

A: The food-versus-fuel debate arises from questions related to the use of agricultural food commodities for the production of alternative fuels. The debate stems from a spike in animal feed costs and food prices in 2008 and the rapid development and expansion of the corn ethanol industry. Currently, 30% of the domestic corn crop is used for ethanol production. Some people fear that the use of corn as a feedstock for alternative fuel production will lead to higher food prices and perhaps even compromise food supplies. Others argue that the rapid increase in food prices in 2008 was the result of high energy costs, not corn ethanol production. The issue has become politically charged. There is little consensus of the role of alternative fuel production on food production and prices.

In order to avoid the controversy surrounding the food-versus-fuel debate, CAAFI and other stakeholders in the U.S. airline industry support the use of feedstocks that do not compromise food availability. Therefore, these entities are interested in feedstocks that are not used for human food production and that, according to some, would not have an impact on food prices or security. Examples of these feedstocks include agriculture residues (e.g., wheat straw, corn stover), dedicated energy crops (switchgrass), woody biomass, MSW, alternative oilseed feedstocks (e.g., algae, *Jatropha*), and nonfood oilseeds (e.g., mustard seed, *Camelina*).

Q: What does the concept of the energy-water-food nexus mean and why is it important to alternative jet fuel?

A: The energy-water-food nexus is a prominent issue among senior business, finance, policy, military, and NGO leaders and refers to the links between energy, water, and food. Because these issues are so closely intertwined, credible analysis of one part of the nexus requires evaluating implications on the other parts. For example, evaluation of crops for energy requires consideration of concerns around food versus fuel and also agriculture's impact on increasingly scarce water resources, including in marginal land such as in arid environments that may not be fit for other types of agriculture. In addition, the evaluation of natural gas requires consideration of extraction techniques on water quality.

Q: What does "land use" mean and why is it important to the future of alternative jet fuel?

A: Land use is an important component of the energy-water-food nexus. The term "land use" in this context refers to unresolved concerns about whether increasing demand for agricultural products in one part of the world, for food or energy crops, drives conversion of forests into agricultural land in other parts of the world such as in Brazil, Indonesia, and Africa. This

issue is of importance for several reasons. First, deforestation is one of the world's largest sources of carbon emissions and has many other social, environmental, and economic impacts. In addition, overturning topsoil for planting, especially the first time once the land is deforested, also releases significant carbon. Land-use implications are difficult to prove, disprove, or quantify. Despite this uncertainty, correctly gauging the impact of alternative jet fuels on land use will be critical to their long-term acceptance.

Q: How may the production of alternative jet fuel affect water resources?

A: Water use is a topic that frequently comes up during the discussion of any kind of alternative fuels, including alternative jet fuel. Depending on the specific way in which feedstocks are recovered and processed, water consumption for the production of alternative jet fuels may be comparable to or larger than that required for conventional jet fuel production. The water impact of alternative jet fuels should be evaluated by considering the feedstocks and conversion technologies separately. There are two components pertaining to feedstocks. In terms of water *consumption*, traditional feedstock crops, such as soybeans, require large amounts of freshwater. In contrast, new bio-derived crops, such as switchgrass, do not need irrigation, and algae can grow in brackish water or seawater. In terms of water *pollution*, fossil feedstocks and traditional feedstock crops contribute runoff from fertilizers and pesticides.

Regarding conversion technologies, the need for cooling drives the water impact. The impact varies widely, from extensive to minimal, with the type of cooling and conversion technology. Fischer-Tropsch requires substantial cooling and is generally more water intensive than hydroprocessing per unit of energy produced.

It should be noted that the United States has extensive laws and regulations governing water, as indicated in Section 3.5.1. Compliance with these laws and regulations should be considered sufficient to meet any concerns about impacts to water resources.

Q: Are there sustainability criteria for alternative jet fuels?

A: Production of alternative jet fuels may affect the environment in several ways, as noted previously. In the United States, there are no mandatory sustainability criteria for alternative fuels. The United States has a full suite of detailed environmental laws and regulations and a legal system to enforce compliance with those laws and regulations—demonstration of compliance with the law should be considered sufficient to establish sustainability according to existing laws and regulations.

There are efforts to develop sustainability standards applicable to development of alternative fuels in general (not only alternative jet fuel). One example is the Roundtable on Sustainable Biofuels (http://rsb.epfl.ch/). These standards aim to include a number of factors, including food security, land and water rights, and fair labor laws. The development of these standards has been difficult because of the complexities and sensitivities around the main considerations that need to be considered. Details for the application of these standards are also still being discussed.

4.2 What Are Some Potential Concerns Regarding Production of Alternative Jet Fuel?

Q: Who can I turn to for help in finding out more about particular production methods or feedstocks?

A: Contact CAAFI through their website (www.caafi.org) or the ATA at info@airlines.org. These organizations are knowledgeable in the application of feedstocks and processes for alternative jet fuels. Renewable fuel trade associations (e.g., Advance Biofuels Association, Low Carbon

Fuel Association) can introduce airports to their members. *Biofuels Digest* and other trade publications are also excellent sources of this information. Fuel suppliers are increasingly present at major air shows and can be contacted at those venues.

Q: What is the biggest challenge in finding the best option for producing alternative jet fuel in my region?

A: The main challenge for alternative jet fuel production is finding the appropriate feedstock. For processing plants using biomass feedstocks, local availability of feedstocks is likely the most important factor. For processing plants using fossil fuels, such as coal or natural gas, easy access to existing transportation infrastructure is the main concern.

Q: We have identified a possible production technology and have plenty of local feedstock; how can we find a company to produce the fuel?

A: Contact CAAFI or ATA. The CAAFI website (www.caafi.org) contains links to many companies that are among their stakeholders. ATA can help identify a fuel expert from one of the airlines that serves your airport. Other sources are the Advanced Biofuels Association, BIO, and the Low Carbon Fuel Association. In addition, several trade publications (e.g., *Biofuels Digest*) contain lists of qualified producers.

Q: Can more than one feedstock be used in a HEFA facility?

A: Yes, in fact most producers will not want to rely on a single feedstock. Multiple plant oils can grow in the capture radius of a HEFA facility.

Q: Can the percentage of alternative jet fuel and other products from an alternative fuel processing facility be altered during the life of the facility?

A: Yes. Alternative jet fuel requires more hydroprocessing capacity than diesel. Once a facility is built for alternative jet fuel, it can always produce more alternative (green) diesel. Typically the maximum amount of alternative jet production is 60%

Q: How much more will alternative jet fuels cost compared to conventional jet fuel? How will the cost differential change with time?

A: According to most pricing scenarios, alternative jet fuels produced from new energy feedstocks and bought only in small quantities will cost more than conventional jet fuel. These initial costs are mitigated by both Congressional subsidies ($1 per gallon in recent years) and the USDA Biomass Crop Assistance Program. Considering the history of food crops, in which the yield per acre has improved over time, it is reasonable to expect that the yield per acre of bio-feedstocks will also increase, resulting in a reduction in their price.

Q: Are there public funding sources that can support feasibility studies for a biofuel facility at or near an airport?

A: Yes. USDA Rural Development has a series of programs to fund these types of studies. State agriculture departments are a source of programs as well. Contact CAAFI for more information.

Q: What constitutes a "rural" alternative jet fuel project that can be supported by USDA?

A: In new rules published in February 2011, the definition of "rural" is greatly expanded. For example, a project constructed in a more-densely populated location using feedstocks from historically rural locations can be eligible. Airports, their clients, and stakeholders should consult with local and national USDA rural development authorities to establish how these new rules are applied in the local area.

Q: Are there limitations on the sources of foreign funding that can be supported by the USDA loan guarantee program?

A: In new rules issued by USDA in February 2011, foreign sources of investment in U.S.-based project developments are now eligible for support through certain USDA programs, including loan guarantees to develop alternative jet fuel projects. While this policy has been executed, regulations on specific USDA programs may be required to capture its intent. Airports and their clients should consult with CAAFI or local or national USDA Rural Development Authorities to establish which programs are eligible. Once this is known, consultation with U.S. Department of Commerce programs such as Invest in America (http://www.investamerica.gov/) may be useful.

4.3 What Are Some of the Potential Concerns Around the Storage, Handling, and Use of Alternative Jet Fuel?

Q: Do airlines support the use of alternative jet fuel?

A: Yes, the U.S. airlines' interest in alternative jet fuel is being coordinated by the ATA. The ATA supports alternative jet fuels as long as they are safe, environmentally friendly, reliable, and economically feasible. Airlines are committed to supporting alternative jet fuel facilities by signing long-term purchase agreements, but their willingness to pay a premium over the cost of conventional fuel will depend on the amount and duration of the premium.

Q: Does alternative jet fuel need any special airport-related infrastructure?

A: No, alternative jet fuel will not be qualified if it cannot be handled by existing airport fueling equipment.

Q: Will alternative jet fuels require duplicate storage or distribution systems at my airport?

A: No, by definition, drop-in fuels do not require duplicate storage or distribution. However, if the fuel is delivered through infrastructure not currently in use, then hookups will be necessary. For example, if an airport currently receives conventional jet fuel through a pipeline from a refinery, and starts to receive alternative jet fuel by railroad, then a hookup between the railroad car and the pipeline will be required.

Q: Is alternative jet fuel really safe to use in all aircraft, including older models?

A: Yes, alternative jet fuel will be thoroughly tested and will not receive certification unless it is safe in all existing gas turbine engines.

Q: Is alternative jet fuel safe to mix with conventional jet fuel in our existing tanks?

A: Yes, alternative jet fuel will be thoroughly tested and will not receive qualification approval from ASTM unless it is safe to mix with conventional jet fuel.

Q: How can I know jet fuel produced by a particular process has been qualified as safe?

A: Alternative jet fuels that are safe are listed under annexes to the alternative fuels specification ASTM D7566. CAAFI can be consulted if there are questions in this regard.

Q: We always test jet fuel before we accept delivery and add it to our fuel tanks. Can we use the same testing methods on regular Jet A and alternative jet fuels?

A: Yes, the same testing procedures will be used for regular Jet A and alternative jet fuel per current plans.

Q: Does alternative jet fuel have more quality control problems than regular fuel?

A: There is no current evidence to indicate that alternative jet fuel have more quality control problems than conventional jet fuel. One concern, however, will be the proliferation of many new fuel providers. This issue is being studied by the FAA and has been highlighted by CAAFI.

SECTION 5

Supporting Materials and Worksheets

5.1 Supporting Material to Evaluate Potential Environmental Benefits of Alternative Jet Fuels

The main potential environmental benefits of alternative jet fuels considered here are life-cycle greenhouse gas and particulate matter ($PM_{2.5}$) emission reductions compared to conventional jet fuel (see Sections 2.4 and 3.5.2). The information provided in Table 4 and Figure 7 can be used for initial evaluation of both potential effects. For more details on this data, please refer to Appendix E.

Another useful resource for quantifying $PM_{2.5}$ benefits is currently in development through ACRP Project 02-23, "Alternative Fuels as a Means to Reduce $PM_{2.5}$ Emissions at Airports." Please check the ACRP website for the status of this project at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2794.

Life-Cycle GHG Emissions

Table 4. Life-cycle GHG emissions expressed as grams CO_2 equivalent (g CO_2e) per MJ of fuel energy content (adapted from Stratton, Wong, and Hileman 2010).

Pathway	Biomass Credit	Recovery	Feedstock Transport	Processing	Fuel Transport	Combustion	WTT N_20	WTT CH_4	Land-Use Change	Total
Crude to conventional jet fuel	0	4.2	1.5	5.5	0.8	73.2	0.1	2.3	0	87.5
Crude to ULS jet fuel	0	4.2	1.5	7.3	0.8	72.9	0.1	2.4	0	89.1
Oil sands to jet fuel	0	19	1.3	5.5	0.5	73.2	0.1	3.1	0	102.7
Oil shale to jet fuel	0	41.2	0.6	3.3	0.6	73.2	0.2	2.5	0	121.5
Natural gas to FT fuel	0	4.6	0	20.2	1.2	70.4	0	4.6	0	101
Coal to FT fuel with (without) carbon capture	0	0.8	0.1	19.4 (117.2)	0.6	70.4	0	5.9 (5.7)	0	97.2 (194.8)
Switchgrass to FT fuel	-222.7	6.4	0.6	152.1	0.5	70.4	0.2	10.3	-19.8 to 0	-2.0 to 17.7
Coal and switchgrass to FT fuel, with carbon capture	-44.3	1.2	0.2	21.9	0.5	70.4	2	4.9	-3.9 to 0	53.0 to 56.9
Soy oil to HEFA/HRJ	-70.5	20.1	1.2	10.3	0.6	70.4	3.6	1.3	0 to 527.2	37.0 to 564.2

Table 4. (Continued).

Pathway	Biomass Credit	Recovery	Feedstock Transport	Processing	Fuel Transport	Combustion	WTT N_2O	WTT CH_4	Land-Use Change	Total
Palm oils to HEFA/HRJ	-70.5	4.9	3.1	10.3	0.6	70.4	5.1	6.3	0 to 667.9	30.1 to 698.0
Rapeseed oil to HEFA/HRJ	-70.5	17.2	3.1	10.3	0.6	70.4	22.4	1.3	0 to 43.0	54.9 to 97.9
Jatropha oil to HEFA/HRJ	-70.5	16.7	1.5	10.3	0.6	70.4	9.1	1.2	0	39.4
Algae oil to HEFA/HRJ	-70.5	29.6	0.3	10.3	0.6	70.4	8.1	1.8	0	50.7
Salicornia to HEFA/HRJ and FT fuel	-105.3	36.8	1.1	38.3	0.5	70.4	4.6	1.3	-41.9 to 0	5.8 to 47.7

Note: Some totals do not sum due to rounding.

Particulate Matter ($PM_{2.5}$)

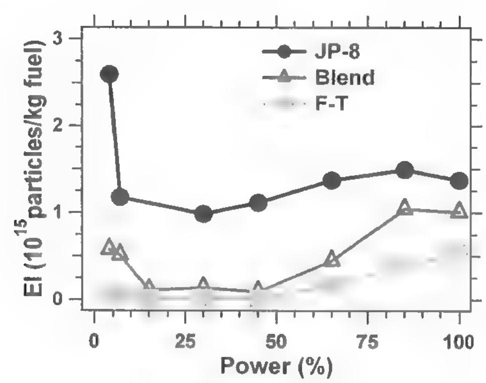

Figure 7. ***Particulate emission index for immediately behind a CFM-56 engine using conventional, Fischer-Tropsch, and blended fuels as measured by alternative aviation fuel experiment (AAFEX). Source: Beyersdorf and Anderson 2009.***

5.2 Worksheets

5.2.1 Worksheet 1: Stakeholder Analysis

Instructions:

1. Use one copy of the worksheet for each stakeholder.
2. Fill out as much information as is available.
3. Keep data for future reference.

Table 5. Stakeholder analysis.

Stakeholder Information	
Stakeholder (Name of entity):	
Role in project: (e.g., airport, airline, feedstock supplier, fuel producer, municipality/local government, public-/private-sector funder)	
Stakeholder mission	
Economic	
Non-economic	
Is project consistent with mission? (yes, maybe/not sure, no)	
Explanation	
Hurdle rate: Describe specific minimum requirements that project must meet to obtain stakeholder's participation	
Economic	
Non-economic	
Does project meet hurdle rate? (yes, maybe/not sure, no)	
Explanation	
Stakeholder concerns and risks	
Economic	
Non-economic	
Has mitigation strategy been developed? (yes, maybe/not sure, no)	
Explanation	
Actions required to obtain/enhance stakeholder participation	
Economic	
Non-economic	
Has a plan been developed to obtain/enhance stakeholder participation? (yes, maybe/not sure, no)	
Explanation	
Stakeholder decision-making process	
Is the stakeholder's internal and external decision-making process fully understood? (yes, maybe/not sure, no)	
What needs to be done/who needs to be consulted to understand decision-making process?	
Explanation	

5.2.2 Worksheet 2: Regulatory Considerations

Use this worksheet to evaluate the regulatory and environmental review considerations of alternative jet fuel projects.

Instructions

1. Use one worksheet for each alternative jet fuel project option under consideration.
2. Note that Table 6 applies to on-airport projects only. If the project is located near-airport or off-airport, Table 6 does not need to be filled out.
3. In Table 6 through Table 8, indicate the likelihood that the project can meet each regulation or consideration:
   a. If the project is certain to meet the regulation or consideration, check "Meets Regulation/Consideration."
   b. If the project can meet the regulation or consideration with some extra effort, check "Likely to Meet Regulation/Consideration."
   c. If the project is unlikely to meet the regulation or consideration even with additional extra effort, check "Does Not Meet Regulation/Consideration."
   d. If more information is needed to provide an answer, check "Need More Information."
4. Count the total of items checked in each category.
5. In Table 9, summarize the total for Table 6 through Table 8, and count the resulting overall total for Worksheet 2.

Worksheet 2: Regulatory Considerations (continued)

Table 6. FAA design standards and environmental regulations requiring FAA unconditional approval of an airport layout plan (for on-airport projects only).

Option:					
Regulatory Considerations for the Proposed Project	**Reference Documentation**	**Meets Regulation**	**Likely to Meet Regulation**	**Does Not Meet Regulation**	**Need More Information**
Complies with airport design specifications.	FAA AC 150/5300-1, Airport Design				
Does not create obstacles to navigable airspace.	FAR Part 77, Objections Affecting Navigable Airspace				
Meets national standards for fuel servicing at airports.	National Fire Protection Association (NFPA) 407, Standard for Aircraft Fuel Servicing				
Complies with NEPA and applicable environmental laws or regulations.	FAA Order 5050.4B, National Environmental Policy Act (NEPA) Implementing Instructions for Airport Projects *Environmental Desk Reference for Airport Actions*				
Development unconditionally approved on the ALP.	FAA Order 5190-6b, Appendix R, Airport Compliance Manual				
Meets minimum standards for commercial aeronautical activities.	FAA Order 5190-7, Minimum Standards for Commercial Aeronautical Activities				
Existing airport and airside infrastructure have adequate funding.*	FAA Vision 100 – Century of Aviation Reauthorization Act				
Existing airport meets FAA RSA requirements.	FAA Vision 100 – Century of Aviation Reauthorization Act; FAA AC 150/5300-1, Airport Design				
Existing airport meets FAA Runway RPZ requirements.	FAA Vision 100 – Century of Aviation Reauthorization Act; FAA AC 150/5300-1, Airport Design				
Federal share of the project is being funded with non-primary entitlements.*	FAA Vision 100 – Century of Aviation Reauthorization Act				
Total					

*This relates only to fuel storage and is limited to non-primary entitlement airports.

6. Using the total for Worksheet 2 in Table 9, grade each option according to the following guidelines (see Section 3.5.2 for more details).
   a. Green: The project can meet all regulations and other considerations. (Only boxes in "Meets All Regulation/Consideration" column are checked.)
   b. Yellow: The project is likely to meet all regulations and other considerations with some extra effort. (Most boxes in "Meets All Regulation/Consideration" column and only a few in "Likely to Meet All Regulation/Consideration" column are checked.)
   c. Red: The project cannot meet all regulatory and other considerations. (One or more boxes in "Does Not Meet Regulation/Consideration" column are checked.)
7. Fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "FAA Regulations and Environmental Review" row of "Worksheet 6: Evaluation Summary."

Worksheet 2: Regulatory Considerations (continued)

Table 7. General land-use compatibility considerations.

Option:					
General Land-Use Compatibility Considerations	**Reference Documentation**	**Meets Consideration**	**Likely to Meet Consideration**	**Does Not Meet Consideration**	**Need More Information**
No part of the proposed project is an obstacle to navigation as defined by the FAA.	FAR Part 77, Objections Affecting Navigable Airspace				
Alternative jet fuel infrastructure does not lay in an area that is of high risk to damage in the event of an accident.	General assessment of ALP relative to runways and runway approach and potential overshoot zones				
Alternative jet fuel infrastructure is not located near high-density residential structures, labor-intensive industries, hazardous material storage facilities, power generation or gas distribution facilities, or concentrations of populations unable to function in an emergency.					
Alternative jet fuel project, including potential planting and storage of crops, will not attract wildlife to the airport that may be a hazard to aircraft.	FAA AC 150/5200-33, Hazardous Wildlife Attractants On or Near Airports				
Total					

Table 8. General environmental permitting considerations.

Option:					
General Environmental Permitting Considerations	**Reference Documentation**	**Meets Consideration**	**Likely to Meet Consideration**	**Does Not Meet Consideration**	**Need More Information**
Permits related to environmental impacts of alternative jet fuel infrastructure on drinking water, groundwater, storm water, and wastewater are obtainable.	See Section 3.5.1				
Permits related to environmental impacts of gaseous and other emissions on ambient air standards are obtainable.	See Section 3.5.1				
Permits related to solid waste disposal, hazardous waste handling and disposal, spill prevention, reporting, and cleanup are obtainable.	See Section 3.5.1				
Permits related to impacts on shared infrastructure such as roads and railways are obtainable.	See Section 3.5.1				
Total					

Worksheet 2: Regulatory Considerations (continued)

Table 9. Summary of Worksheet 2—Regulatory considerations.

Option:				
Summary of Worksheet 2 – Regulatory Considerations	Meets Regulation/Consideration	Likely to Meet Regulation/Consideration	Does Not Meet Regulation/Consideration	Need More Information
Worksheet 2, Table 6: FAA design standards and environmental regulations requiring FAA unconditional approval of an airport layout plan (for on-airport projects only)				
Worksheet 2, Table 7: General land-use compatibility considerations				
Worksheet 2, Table 8: General environmental permitting considerations				
Total Worksheet 2				
Worksheet 2 grading (green, yellow, or red)				

5.2.3 Worksheet 3: Energy Policy Considerations

This worksheet is meant to identify and keep a record of potential entities and their policies that may support an alternative jet fuel project. This can be a useful resource for building a business plan.

Instructions

1. Use one worksheet for each alternative jet fuel project under consideration.
2. For each entity and policy element, check the "Applicable," "May Be Applicable," "Not Applicable," or "Need More Information" box.
3. Space is provided to include other entities or policies identified by the reader.
4. Count the total number of items checked in each category.
5. Grade each option according to the following guidelines (see Section 3.5.2 for more details):
   - Green: All or most policies are applicable. (Most or all boxes checked are in the "Applicable" column.)
   - Yellow: Some policies are applicable and most may be applicable. (Some boxes checked are in the "Applicable" column, most boxes checked are in the "May Be Applicable" column, and some boxes checked are in the "Not Applicable" column.)
   - Red: No policies are applicable. (Most boxes checked are in the "Not Applicable" column.)

   Note: This evaluation is intended to reflect the possible strength of support from a number of entities and their policies on alternative jet fuels for individual project options. A grading of red does not mean that a project is not viable. Such a grading only indicates that the project does not appear to benefit from the potential support of the entities listed in the worksheet. This may put a given project at a disadvantage compared to other projects that may get a higher grade for energy policy consideration.

6. Fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "Energy Policy" row of "Worksheet 6: Evaluation Summary."

Worksheet 3: Energy Policy Considerations (continued)

Table 10. Energy policy considerations.

Option:							
Entity		**Energy Policy Elements**	**Significance to Alternative Jet Fuel Projects**	**Applicable**	**May Be Applicable**	**Not Applicable**	**Need More Information**
White House		Explicit support for aviation biofuels	White House policy statements can help airport leadership establish priorities and identify agencies tasked to implement alternative fuel support programs.				
		Other:					
		Other:					
FAA		PARTNER Project 28	Establish greenhouse gas benefits for specific feedstocks and processes.				
		PARTNER Project 20	Establish particle matter outcomes.				
		VALE	Possible synergies with alternative jet fuel projects.				
		Sustainable Master Plan Pilot Program	Integrate alternative jet fuel projects with airport's sustainability initiatives.				
		Other:					
		Other:					
U.S. Military		Commitments from Air Force and Navy to alternative fuels	Can help support alternative jet fuel projects if co-located with military customers.				
		Other:					
		Other:					
Other government	USDA	BCAP	Can provide support to feedstock production.				
		Value added grants	Can finance project evaluation and development.				
		Other:					
		Other:					
	Other	Other:					
		Other:					
Public/private partnerships and coalitions	CAAFI	CAAFI's mission of promoting alternative jet fuels	Provide support for alternative jet fuel projects, including technical information, contacts, and technical assistance.				
		Other:					

Worksheet 3: Energy Policy Considerations (continued)

Table 10. (Continued).

Option:

Entity		Energy Policy Elements	Significance to Alternative Jet Fuel Projects	Applicable	May Be Applicable	Not Applicable	Need More Information
		Other:					
	ATA/DLA Alliance	Joint policies for purchase of alternative fuels	Can support alternative jet fuel projects via off-take agreements.				
		Other:					
		Other:					
	Farm to Fly	Support deployment of alternative jet fuel	Provide support for alternative jet fuel projects, including technical information and contacts.				
		Other:					
		Other:					
NGOs	IATA	Commitment to carbon-neutral growth by 2020	Alignment with long-term interests of airlines				
		Other:					
	ATA	Support of alternative aviation fuels	Alignment with long-term interests of airlines				
		Other:					
	ACI–NA	ACI–NA Environmental Goals	Alignment with goals of ACI–NA				
		Other:					
	SAFUG	Support of alternative aviation fuels	Support of coalition members				
		Other:					
	Other NGO	Other:					
		Other:					
	Other NGO	Other:					
Total		Other:					
Worksheet 3 grading (green, yellow, or red)							

5.2.4 Worksheet 4: Logistical Considerations

Use this worksheet to evaluate the logistical considerations of alternative jet fuel projects.

Instructions

1. Fill out Table 11 for the current way in which the airport is supplied with conventional jet fuel. This helps determine the baseline for comparing other options. Do not provide information in the grayed-out cells.
2. Fill out a separate Table 12 for each alternative jet fuel project under consideration.
3. Grade each option according to the following guidelines (see Section 3.5.3 for more details):
   - Green: All or most transportation occurs by pipeline or rail/barge with minimal or no truck transportation; all transportation and storage infrastructure is in place.
   - Yellow: Some truck transportation is required. Some minor transportation and storage infrastructure needs to be built.
   - Red: Truck transportation over long distances is required. Major transportation and storage infrastructure elements need to be built.

   Note: It is important to compare the proposed options to the existing way of bringing jet fuel to the airport. For example, a yellow grade is appropriate if truck transportation is the only possibility for both the alternative jet fuel and the conventional jet fuel.
4. Fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "Logistical" row of "Worksheet 6: Evaluation Summary."

Table 11. Current option—supply of conventional jet fuel to airport.

Option: Current Supply of Conventional Jet Fuel				
Transportation Infrastructure	Transportation Mode and Distance of Feedstock To:		Transportation Mode and Distance of Conventional Jet Fuel from Processing Plant To:	
	Intermediate Storage (If Needed)	Processing Plant	Intermediate Storage (If Needed)	Airport
Truck				
Rail				
Barge				
Pipeline				
Other				
Existing or new?				

Storage Infrastructure	Storage of Feedstock At:		Storage of Finished Conventional Jet Fuel At:	
	Intermediate Location (If Needed)	Processing Plant	Intermediate Storage (If Needed)	Airport
Existing or new?				

Notes:

- *For transportation options, indicate approximate distances. Also, indicate if the airport expects to build any new transportation infrastructure in the foreseeable future.*
- *Indicate if the airport expects to build any new storage infrastructure in the foreseeable future.*

Worksheet 4: Logistical Considerations (continued)

Table 12. Alternative jet fuel project option—supply of alternative jet fuel to airport.

Option:				
Transportation Infrastructure	**Transportation Mode and Distance of Feedstock To:**		**Transportation Mode and Distance of Finished Alternative Jet Fuel from Processing Plant To:**	
	Intermediate Storage (If Needed)	**Processing Plant**	**Intermediate Storage (If Needed)**	**Airport**
Truck				
Rail				
Barge				
Pipeline				
Other				
Existing or new?				

Storage Infrastructure	**Storage of Feedstock At:**		**Storage of Finished Alternative Jet Fuel At:**	
	Intermediate Location (If Needed)	**Processing Plant**	**Intermediate Storage (If Needed)**	**Airport**
Existing or new?				

Notes:

- *For transportation options, indicate approximate distances. Also, indicate if the airport expects to build any new transportation infrastructure in the foreseeable future.*
- *Indicate if the airport expects to build any new storage infrastructure in the foreseeable future.*

Worksheet 4 grading (green, yellow, or red)	

5.2.5 Worksheet 5: Financial Considerations

Instructions

1. Use one worksheet for each alternative jet fuel project option under consideration.
2. Start with Step 1 in Figure 8 and follow the arrows in the diagram according to the answers to the questions.
3. Grade each option according to the results of the diagram in Figure 8 (see Section 3.5.4 for more information). Repeat exercise, as necessary, as more information becomes available.
4. Fill in the appropriate circle in the "Green," "Yellow," or "Red" column in the "Financial" row of "Worksheet 6: Evaluation Summary."

Worksheet 5: Financial Considerations (continued)

Option: ____________________

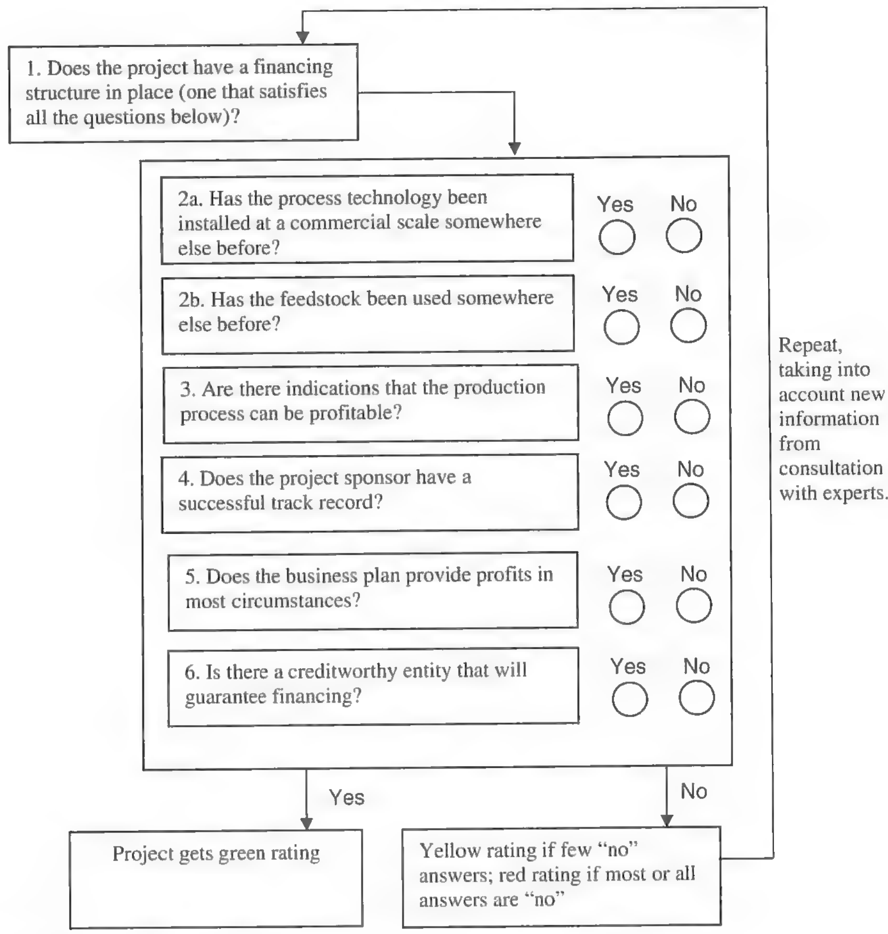

Figure 8. Diagram to evaluate financial considerations.

Worksheet 4 grading (green, yellow, or red)	

5.2.6 Worksheet 6: Evaluation Summary

Use this worksheet to summarize the evaluation of each alternative jet fuel option under consideration.

Instructions

1. For each alternative jet fuel option under consideration, complete Table 13 using the results from Worksheets 2 through 5 and Section 3.5.2, as indicated.
2. Count the total number marks in the "Green," "Yellow," and "Red" columns for the "Total" row.

Worksheet 6: Evaluation Summary (continued)

Table 13. Evaluation summary.

Option:			
Evaluation Criteria	Rating		
	Green	Yellow	Red
Regulatory			
• FAA regulations and environmental review (Worksheet 2)	◯	◯	◯
• Energy policy (Worksheet 3)	◯	◯	◯
Environmental			
• Life-cycle GHG (see section 3.5.2)	◯	◯	◯
• Particulate matter (see section 3.5.2)	◯	◯	◯
Logistical (Worksheet 4)	◯	◯	◯
Financial (Worksheet 5)	◯	◯	◯
Total			

SECTION 6

Bibliography

6.1 FAA Advisory Circulars, Orders, Regulations, and Peripheral Documentation

Federal Aviation Administration. Aircraft Fuel Storage, Handling, and Dispensing on Airports. AC 150/5230-4A. 2004. Available at http://www.faa.gov/documentLibrary/media/advisory_circular/150-5230-4A/150_5230_4a.pdf.

Federal Aviation Administration. Airport Design. AC 150/5300-13. 1989. Available at http://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5300_13.pdf.

Federal Aviation Administration. Airport Master Plans. AC 150/5070-6B. 2007. Available at http://www.faa.gov/documentLibrary/media/advisory_circular/150-5230-4A/150_5230_4a.pdf.

Federal Aviation Administration. "Best Practices for Environmental Impact Statement (EIS) Management." 2002. Available at http://www.faa.gov/airports/environmental/eis_best_practices/.

Federal Aviation Administration. *Environmental Desk Reference for Airport Actions.* 2007. Available at http://www.faa.gov/airports/environmental/environmental_desk_ref/media/desk_ref.pdf.

Federal Aviation Administration. Environmental Impacts: Policies and Procedures. Order 1050.1E. 2004. Available at http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgOrders.nsf/7868430l3bf2d049852569810075c599/9552db552fd4495b862570660068adb1/$FILE/Order1050-1E.pdf.

Federal Aviation Administration. *FAA Airport Compliance Manual.* Order 5190.6B. 2009. Available at http://www.faa.gov/airports/resources/publications/orders/compliance_5190_6/media/5190_6b_appR.pdf.

Federal Aviation Administration. Federal Aviation Regulations, Part 77, Objections Affecting Navigable Airspace. 1993. Available at https://oeaaa.faa.gov/oeaaa/external/content/FAR_Part77.pdf.

Federal Aviation Administration. Form 7460-1, Notice of Proposed Construction or Alteration. 1999. Available at http://www.faa.gov/documentLibrary/media/form/faa7460_1.pdf.

Federal Aviation Administration. Hazardous Wildlife Attractants on or near Airports. AC 150/5200-33. 1997. Available at http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/53bdbf1c5aa1083986256c690074ebab/$FILE/150-5200-33.pdf.

Federal Aviation Administration. Minimum Standards for Commercial Aeronautical Activity. AC 150/5190-7. 2006. Available at http://www.faa.gov/documentLibrary/media/advisory_circular/150-5190-7/150_5190_7.pdf.

Federal Aviation Administration. National Environmental Policy Act (NEPA) Implementing Instructions for Airport Projects. Order 5050.4B. 2006. Available at http://www.faa.gov/airports/resources/publications/orders/environmental_5050_4/.

National Fire Protection Association. Standard for Aircraft Fuel Servicing, NFPA 407. 2007.

6.2 State Environmental Permitting Guides

Table 14 lists links to guidelines regarding alternative fuels published by several states, regional authorities, and the EPA. This list is not comprehensive and is expected to change.

6.3 Certification

American Society of Testing and Materials. Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. D7566-10a. 2010.

Table 14. State's environmental permitting guides.

State/Region	Reference
Alabama	http://www.adeca.alabama.gov/C17/ATF/Document%20Library/Regulatory%20Requirements%20for%20Biofuel%20Production%20Facilities.pdf
Arizona	http://desertbiofuels.org/attachments/046_ArizonaBiodieselRegulatoryEnvironment.pdf
Arkansas	http://www.winrock.org/us_programs/files/Winrock_US_AR_biodiesel_final_report.pdf
California	http://www.arb.ca.gov/fuels/lcfs/reportingtool/biofuelregistration.htm
Connecticut	http://www.ct.gov/dps/lib/dps/office_of_education_and_data_management_files/environmental_requirements.pdf
Florida	http://www.dep.state.fl.us/waste/quick_topics/publications/shw/solid_waste/Biofuels_Trifold_Brochure.pdf
Illinois	http://www.epa.state.il.us/agriculture/building-an-ethanol-plant.pdf
Iowa	http://www.iowalifechanging.com/business/downloads/Reg_Biodiesel.pdf
Kansas	http://www.ksda.gov/includes/document_center/renewable_energy/Fueled_by_Farmers/ProducingBiofuelsinKansas.pdf
Kentucky	http://energy.ky.gov/biofuels/Documents/biofuelconsiderations.pdf
Maine	http://www.maine.gov/oeis/docs/2008_1_Liquid-Biofuels-Policy.pdf
Maryland	http://www.mde.state.md.us/programs/ResearchCenter/Documents/www.mde.state.md.us/assets/document/Biodiesel_Permitting_Summary_08.pdf
Minnesota	http://www.pca.state.mn.us/index.php/topics/energy/alternative-fuels/biodiesel/biodiesel-information-for-facilities.html
Missouri	http://www.dnr.mo.gov/pubs/pub1347.pdf
Montana	http://www.deq.mt.gov/energy/bioenergy/BioEnergyGuidebook2010.mcpx
Nebraska	http://www.cleanfuelsdc.org/pubs/documents/ethanol_plant_guide.pdf
New Hampshire	http://des.nh.gov/organization/commissioner/pip/factsheets/co/documents/co-16.pdf
New Mexico	http://www.edd.state.nm.us/greenEconomy/overview/nmGreenBusinessPermittingGuide.pdf
New York	http://www.dec.ny.gov/energy/43310.html
Ohio	http://www.epa.state.oh.us/portals/41/sb/publications/biodieselguide.pdf
Oklahoma	http://www.ok.gov/~okag/forms/cps/fuelalcoholtitle35.pdf
Oregon	http://oregon.gov/ENERGY/RENEW/Biomass/Producing.shtml http://www.oregon.gov/ENERGY/RENEW/Biomass/permits.shtml#Biodiesel_Production http://www.oregon.gov/ENERGY/RENEW/Biomass/docs/BioQA-final.pdf
Virginia	http://www.deq.state.va.us/osba/pdf/VDEQBiodieselPrimer2008.pdf
Washington	http://www.ora.wa.gov/documents/ENV_008_08.pdf http://www.ora.wa.gov/documents/ENV_010_08.pdf http://www.ora.wa.gov/documents/pub_BiodieselSmallFactSheet.pdf
Wisconsin	http://energyindependence.wi.gov/docview.asp?docid=11265&locid=160 - biofuels facilities
Southeast Region	http://www.southeastdiesel.org/Photos/So%20you%20want%20to%20make%20biodiesel11.15.07.pdf
Northeast Region	http://www.nrbp.org/pdfs/pub09.pdf
EPA	http://www.epa.gov/region07/priorities/agriculture/pdf/biodiesel_manual.pdf

American Society of Testing and Materials. Standard Specification for Aviation Turbine Fuels. D1655-10. 2010.

Federal Aviation Administration. Approval of Propulsion Fuels and Lubricating Oils. AC 20-24C. 2010. Available at http://www.faa.gov/AIRCRAFT/DRAFT_DOCS/media/DraftAC20_24C.doc.

6.4 Feedstocks for Alternative Jet Fuels

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Mantague, A. Slayton, and J. Lukas. *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover.* Report number NREL/TP-510-32438. U.S. Department of Energy, National Renewable Energy Laboratory, 2002.

Al-Zuhair, S. "Production of Biodiesel: Possibilities and Challenges." *Biofuels, Bioproducts and Biorefining,* Vol. 1, No. 1, September 2007, 57–66.

Australian Commonwealth Scientific and Industrial Research Organisation. Meat Technology Information Sheet—Tallow. 1997. Available at http://www.redmeatinnovation.com.au/innovation-areas/value-adding/co-products/mla-newsletters/tallow.

Baffes, J., and T. Haniotis. *Placing the 2006/08 Commodity Price Boom into Perspective.* The World Bank, 2010. Report number WPS5371. Available at http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2010/07/21/000158349_20100721110120/Rendered/PDF/WPS5371.pdf.

Bauen, A., J. Howes, L. Bertuccioli, and C. Chudziak. *Review of the Potential for Biofuels in Aviation.* E4tech for the Committee on Climate Change, 2009. Available at http://downloads.theccc.org.uk/Aviation%20Report%2009/E4tech%20(2009),%20Review%20of%20the%20potential%20for%20biofuels%20in%20aviation.pdf.

Bowen, B. H., and M. W. Irwin. *Coal Transportation Economics.* The Energy Center and Discovery Park, Purdue University, 2007. Available at http://www.purdue.edu/discoverypark/energy/pdfs/cctr/outreach/Basics7-Transportation-Apr07.pdf.

Brechbill, S. C., and W. E. Tyner. "The Economics of Biomass Collection, Transportation and Supply to Indiana Cellulosic and Electric Utility Facilities." Working Paper 08-03. Purdue University, Department of Agricultural Economics, 2008. Available at http://ageconsearch.umn.edu/bitstream/6148/2/wp080003.pdf.

Brown, L. "Massive Diversion of U.S. Grain to Fuel Cars Is Raising World Food Prices." Earth Policy Institute, 2007. Available at http://www.earth-policy.org/index.php?/plan_b_updates/2007/update65.

Busby, D., R. D. Little, S. Shaik, A. Martins, F. Epplin, S. Hwang, B. S. Baldwin, and C. M. Taliaferro. "Yield and Production Costs for Three Potential Dedicated Energy Crops in Mississippi and Oklahoma Environments." Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Mobile, Alabama, February 2007. http://ageconsearch.umn.edu/bitstream/34854/1/sp07bu07.pdf.

Canakci, M., and H. Sanli. "Biodiesel Production from Various Feedstocks and Their Effects on the Fuel Properties." *Journal of Industrial Microbiology and Biotechnology,* Vol. 35, 2008, 431–441.

Carolan, J. E., S. V. Joshi, and B. E. Dale. "Technical and Financial Feasibility Analysis of Distributed Bioprocessing Using Regional Biomass Pre-Processing Centers." *Journal of Agricultural and Food Industrial Organization,* Vol. 5, No. 2, 2007.

Carriquiry, M., and B. A. Babcock. "A Billion Gallons of Biodiesel: Who Benefits?" *Iowa Ag Review,* Vol. 14, No. 1, 2008, 6–8.

Congressional Budget Office. "The Impact of Ethanol Use on Food Prices and Greenhouse-Gas Emissions." 2009. Available at http://www.cbo.gov/ftpdocs/100xx/doc10057/04-08-Ethanol.pdf.

Dale, B. E., B. D. Bals, S. Kim, and P. Erank. "Biofuels Done Right: Land Efficient Animal Feeds Enable Large Environmental and Energy Benefits." *Environmental Science and Technology,* Vol. 44, No. 22, 2010, 8385–8389.

Eidman, V. R. "Economic Parameters for Corn Ethanol and Biodiesel Production." *Journal of Agricultural and Applied Economics,* Vol. 39, No. 2, 2007, 345–356.

Food and Agriculture Organization of the United Nations. "*Jatropha*—A Bioenergy Crop for the Poor." 2009. Available at http://www.fao.org/news/story/en/item/44142/icode/.

Gallagher, P. W. "Energy Production with Biomass: What Are the Prospects?" *Choices,* Vol. 21, No. 1, 2006, 21–25.

Hess, J., C. T. Wright, and K. L. Kenney. "Cellulosic Biomass Feedstocks and Logistics for Ethanol Production." *Biofuels, Bioproducts and Biorefining,* Vol. 1, 2007, 181–190.

International Air Transport Association. *IATA Alternative Fuels Report.* IATA 2009 Report on Alternative Fuels. 2009. Available at http://www.iata.org/SiteCollectionDocuments/Documents/IATA2009ReportonAlternativeFuelsonlineversion.pdf.

Khanna, M., B. Dhungana, and J. Clifton-Brown. "Costs of Producing *Miscanthus* and Switchgrass for Bioenergy in Illinois." *Biomass and Bioenergy,* Vol. 32, 2008, 482–493.

Knothe, G. "Biodiesel: Current Trends and Properties." *Topics in Catalysis,* Vol. 53, 2010, 714–720.

Kumar, A., and S. Sokhansanj. "Switchgrass (*Panicum virgatum,* L.) Delivery to a Biorefinery Using Integrated Biomass Supply Analysis and Logistics (IBSAL) Model." *Bioresource Technology,* Vol. 98, No. 5, March 2007, 1033–1044.

Lane, J. "Pulp Non-Fiction: Biofuels a Ray of Sunshine in a Gloomy Season." *Biofuels Digest,* 2010. Available at http://biofuelsdigest.com/bdigest/2011/02/18/pulp-non-fiction-biofuels-a-ray-of-sunshine-in-a-gloomy-season/.

Lazarus, W. F. "Energy Crop Production Costs and Breakeven Prices under Minnesota Conditions." Staff Paper P08-11. University of Minnesota Department of Applied Economics, 2008. Available at http://ageconsearch.umn.edu/handle/45655.

Leistritz, F. L., and N. M. Hodur. "Biofuels: A Major Rural Economic Development Opportunity." *Biofuels, Bioproducts and Biorefining* Vol. 2, No. 6, 2008, 501–504.

Lewandowski, I., J. M. O. Scurlock, E. Lindvall, and M. Christou. "The Development and Current Status of Perennial Rhizomatous Grasses as Energy Crops in the U.S. and Europe." *Biomass and Bioenergy,* Vol. 25, 2003, 335–361.

Mapemba, L. D., F. Epplin, C. M. Taliaferro, and R. L. Huhnke. "Biorefinery Feedstock Production on Conservation Reserve Program Land." *Review of Agricultural Economics,* Vol. 29, No. 2, 2007, 227–246.

Mark, T., P. Darby, and M. Salassi. "What Does the Introduction of Energy Crops Mean for the Crop Mix and Cellulosic Ethanol Plant Location in Louisiana?" Annual Meeting. Orlando, FL: Southern Agricultural Economics Association, 2010.

Maung, T. A., and B. A. McCarl. "Economics of Biomass Fuels for Electricity Production: A Case Study with Crop Residues." Annual Meeting. Orlando, FL: American Agricultural Economics Association, 2008.

Milbrandt, A. "A Geographic Perspective on the Current Biomass Resource Availability in the United States." NREL/TP-560-39181. National Renewable Energy Laboratory, 2005.

Moser, B. R. "Biodiesel Production, Properties, and Feedstocks." *In Vitro Cellular & Developmental Biology—Plant,* Vol. 45, No. 3, 2009, 229–266.

Naik, S. N., V. V. Goud, P. K. Route, and A. K. Dalai. "Production of First and Second Generation Biofuels: A Comprehensive Review." *Renewable and Sustainable Energy Reviews,* Vol. 14, No. 2, 2010, 578–597.

Natural Gas Supply Association. "Natural Gas Distribution." 2010. Available at http://www.naturalgas.org/naturalgas/distribution.asp.

Neumann, A., and C. von Hirschhausen. "Long-Term Contracts for Natural Gas—An Empirical Analysis." In *9th ISNIE Conference.* Barcelona, Spain: International Society for New Institutional Economics, 2005.

Ng, J. H., H. K. Ng, and S. Gan. "Recent Trends in Policies, Socioeconomy and Future Directions of the Biodiesel Industry." *Clean Technologies and Environmental Policy,* Vol. 12, 2009, 213–228.

Nyren, P. E., E. Eriksmoen, G. Bradbury, M. Halverson, E. Aberle, K. Nichols, and M. Liebig. The Evaluation of Selected Perennial Grasses for Biofuel Production in Central and Western North Dakota. North Dakota State University Central Grasslands Research Extension Center, 2007. Available at http://www.ag.ndsu.edu/archive/streeter/2007report/Grasses_Biofuel.htm.

Paulson, N. D., and R. G. Ginder. "The Growth and Direction of the Biodiesel Industry in the United States." Working Paper 07-WP 448. Center for Agricultural and Rural Development, Iowa State University, 2007. Available at http://www.card.iastate.edu/publications/DBS/PDFFiles/07wp448.pdf.

Petrolia, D. R. "The Economics of Harvesting and Transporting Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota." *Biomass and Bioenergy,* Vol. 32, No. 7, July 2008, 603–612.

Qiang, L., W. Du, and D. Liu. "Perspectives of Microbial Oils for Biodiesel Production." *Applied Microbiology and Biotechnology,* Vol. 80, 2008, 749–756.

Sagar, A. D., and S. Kartha. "Bioenergy and Sustainable Development?" *Annual Review of Environment and Resources,* Vol. 32, 2007, 131–167.

Shi, A. Z., L. P. Koh, and H. T. W. Tan. "The Biofuel Potential of Municipal Solid Waste." *GCB Bioenergy,* Vol. 1, No. 5, 2009, 317–320.

Sokhansanj, S., and A. F. Turhollow. "Biomass Densification—Cubing Operations and Costs for Corn Stover." *Applied Engineering in Agriculture,* Vol. 20, No. 4, 2004, 495–499.

Stratton, R. W., H. M. Wong, and J. I. Hileman. *Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels.* Project 28 Report, version 1.2. PARTNER 2010. Available at http://web.mit.edu/aeroastro/partner/projects/project28.html.

U.S. Department of Agriculture Cooperative Extension Service. Algae for Biodiesel Production. 2010. Available at http://www.extension.org/pages/Algae_for_Biofuel_Productioncitations.

U.S. Department of Agriculture Cooperative Extension Service. Factsheet on Mustard as a Biodiesel Feedstock. 2010. Available at http://www.extension.org/pages/Oilseed_Crops_for_Biodiesel_Production#Mustard.

U.S. Department of Agriculture Cooperative Extension Service. Introduction to Biodiesel. 2010. Available at http://www.extension.org/pages/Introduction_to_Biodiesel.

U.S. Department of Agriculture Cooperative Extension Service. *Miscanthus* for Biofuel Production. 2010. Available at http://www.extension.org/pages/Miscanthus_for_Biofuel_Production.

U.S. Department of Agriculture Cooperative Extension Service. Oilseed Crops for Biodiesel Production. 2010. Available at http://www.extension.org/pages/Oilseed_Crops_for_Biodiesel_Production#Rapeseed_and_Canola.

U.S. Department of Agriculture Cooperative Extension Service. Rapeseed and Canola for Biodiesel Production. 2010. Available at http://www.extension.org/pages/Rapeseed_and_Canola_for_Biodiesel_Production.

U.S. Department of Agriculture Cooperative Extension Service. Switchgrass for Biofuel Production. 2010. Available at http://www.extension.org/pages/Switchgrass_for_Biofuel_Production.

U.S. Department of Agriculture Cooperative Extension Service. Waste Oil and Grease for Biodiesel Production. 2010. Available at http://www.extension.org/pages/Used_and_Waste_Oil_and_Grease_for_Biodiesel.

U.S. Department of Agriculture Farm Services Agency. Biomass Crop Assistance Program Fact Sheet. 2010. Available at http://www.fsa.usda.gov/Internet/FSA_File/bcapoctrules.pdf.

U.S. Department of Agriculture Rural Business-Cooperative Service. Biorefinery Assistance Guaranteed Loans. 7 CFR Parts 4279, 4287 and 4288. 2010. Available at http://www.rurdev.usda.gov/rbs/busp/9003%20ProposedRule%2004-16-2010.pdf.

U.S. Department of Agriculture, Iowa Rural Development. Business and Cooperative Programs. 2010. Available at http://www.rurdev.usda.gov/ia/rbs.html.

U.S. Department of Agriculture. "Agricultural Contracting Update: Contracts in 2008." Economic Information Bulletin No. 72. 2011. Available at http://ageconsearch.umn.edu/handle/101279.

U.S. Department of Agriculture. Crop and Livestock Insurance. 2010. Available at http://www.apfo.usda.gov/FSA/webapp?area=home&subject=prsu&topic=landing.

U.S. Department of Agriculture. Rural Business Enterprise Grants (RBEG) Program. 2010. Available at http://www.rurdev.usda.gov/rbs/busp/rbeg.htm.

U.S. Department of Agriculture. Value-Added Producer Grants (VAPG). 2010. Available at http://www.rurdev.usda.gov/rbs/coops/vadg.htm.

U.S. Department of Agriculture. "World Agriculture Supply and Demand Estimates." 2011. Available at http://www.usda.gov/oce/commodity/wasde/latest.pdf.

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. National Algal Biofuels Technology Roadmap. 2010. Available at http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf.

U.S. Department of Energy. Alternative Fuels and Advanced Vehicles Data Center—Biodiesel. 2010. Available at http://www.afdc.energy.gov/afdc/fuels/biodiesel.html.

U.S. Department of Energy. "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply." 2005. Available at http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf.

U.S. Department of Energy. Roadmap for Agricultural Biomass Feedstock Supply in the United States. 2003. Available at http://www.inl.gov/technicalpublications/Documents/3323197.pdf.

U.S. Energy Information Administration. Delivery and Storage of Natural Gas. 2010. Available at http://tonto.eia.doe.gov/energyexplained/index.cfm?page=natural_gas_delivery.

U.S. Environmental Protection Agency, Office of Solid Waste. "U.S. EPA Waste Management Perspective: The Need for Integrated Materials Management" 2007. Available at http://www.frederickcountymd.gov/documents/Board%20of%20County%20Commissioners/Solid%20Waste%20Forum%202007/Rick%20Brandes%20EPA%20Presentation.pdf.

USDA. Price Support. U.S. Department of Agriculture, 2010. Available at http://www.apfo.usda.gov/FSA/webapp?area=home&subject=prsu&topic=landing.

Verrengia, J. Algae-to-Fuel Research Enjoys Resurgence at NREL. 2009. Available at http://www.nrel.gov/features/20090403_algae.html.

Vidal, J. "One Quarter of U.S. Grain Crops Fed to Cars—Not People, New Figures Show." *The Guardian,* January 22, 2010.

Williams, R. B. "Biofuels from Municipal Wastes—Background Discussion Paper." University of California at Davis, Department of Biological and Agricultural Engineering, 2007. Available at http://biomass.ucdavis.edu/materials/reports%20and%20publications/2007/2007_Annual_Forum_Background_Paper.pdf.

Wiltsee, G. *Urban Waste Grease Resource Assessment.* NREL/SR-570-26141. U.S. Department of Energy, National Renewable Energy Laboratory, 1998. Available at http://www.epa.gov/region9/waste/biodiesel/docs/NRELwaste-grease-assessment.pdf.

6.5 Production Technologies for Alternative Jet Fuels

Altman, R. "Sustainable Alternative Jet Fuel for Carbon Neutral Growth 'Taking Off'!" In Eco Aviation Conference, *Air Transport World,* Washington, D.C., 2010.

Anumakonda, A. "Greening Global Aviation." Paper presented at MRO Americas, Phoenix, AZ, 2010.

Bauen, A., J. Howes, L. Bertuccioli, and C. Chudziak. *Review of the Potential for Biofuels in Aviation.* E4tech for the Committee on Climate Change, 2009. Available at http://downloads.theccc.org.uk/Aviation%20Report%2009/E4tech%20(2009),%20Review%20of%20the%20potential%20for%20biofuels%20in%20aviation.pdf.

Herzog, H. J., and D. Golomb. "Carbon Capture and Storage from Fossil Fuel Use." In *Encyclopedia of Energy,* edited by C. J. Cleveland, 277–287. New York: Elsevier Science Inc., 2004.

Hileman, J., D. Ortiz, J. Bartis, H. Wong, P. Donohoo, M. Weiss, and I. Waitz. Near Term Feasibility of Alternative Jet Fuel. PARTNER-COE-2009-001. PARTNER Project 28, 2009. Available at http://web.mit.edu/aeroastro/partner/reports/proj17/altfuelfeasrpt.pdf.

International Air Transport Association. *IATA Alternative Fuels Report.* IATA 2009 Report on Alternative Fuels. 2009. Available at http://www.iata.org/SiteCollectionDocuments/Documents/IATA2009ReportonAlternativeFuelsonlineversion.pdf.

Massachusetts Institute of Technology. Carbon Capture and Sequestration Technologies Program at MIT. 2011. Available at http://sequestration.mit.edu.

National Advanced Biofuels Consortium. National Advanced Biofuels Consortium Process Strategies. 2010. Available at http://www.nabcprojects.org/process_strategies.html.

National Energy Technology Laboratory. Technologies: Carbon Sequestration. 2011. Available at http://www.netl.doe.gov/technologies/carbon_seq/index.html.

Shi, A. Z., L. P. Koh, and H. T. W. Tan. "The Biofuel Potential of Municipal Solid Waste." *GCB Bioenergy,* Vol. 1, No. 5, 2009, 317–320.

U.S. Environmental Protection Agency, Office of Solid Waste. "U.S. EPA Waste Management Perspective: The Need for Integrated Materials Management" 2007. Available at http://www.frederickcountymd.gov/documents/Board%20of%20County%20Commissioners/Solid%20Waste%20Forum%202007/Rick%20Brandes%20EPA%20Presentation.pdf.

U.S. Energy Information Administration. Ranking of U.S. Refineries. 2011. Available at http://www.eia.doe.gov/neic/rankings/refineries.htm.

Williams, R. B. "Biofuels from Municipal Wastes—Background Discussion Paper." University of California at Davis, Department of Biological and Agricultural Engineering, 2007. Available at http://biomass.ucdavis.edu/materials/reports%20and%20publications/2007/2007_Annual_Forum_Background_Paper.pdf.

Wiltsee, G. *Urban Waste Grease Resource Assessment.* NREL/SR-570-26141. U.S. Department of Energy, National Renewable Energy Laboratory, 1998. Available at http://www.epa.gov/region9/waste/biodiesel/docs/NRELwaste-grease-assessment.pdf.

6.6 Air Quality and Greenhouse Gas Benefits

Congressional Research Service. Department of Defense Fuel Spending, Supply, Acquisition, and Policy. 2009. Available at http://www.fas.org/sgp/crs/natsec/R40459.pdf.

Environmental Protection Agency. Energy Policy Act of 2005. Public Law 109-58. 2005. Available at http://www.epa.gov/oust/fedlaws/publ_109-058.pdf.

Environmental Protection Agency. *Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft.* Report EPA420-R-99-013. 1999. Available at http://www.epa.gov/oms/regs/nonroad/aviation/r99013.pdf.

European Commission. Emissions Trading System (EU ETS). 2010. Available at http://ec.europa.eu/clima/policies/ets/index_en.htm.

European Commission. Establishing a Scheme for Greenhouse Gas Emission Allowance Trading Within the Community and Amending Council Directive 96/61/EC. Directive 2003/87/EC. 2003. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:275:0032:0046:en:pdf.

Federal Aviation Administration. *Air Quality Procedures for Civilian Airports and Air Force Bases.* Report FAA-AEE-97-03. 1997. Available at http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/media/Handbook.pdf.

Federal Aviation Administration. Hazardous Wildlife Attractants on or near Airports. AC 150/5200-33. 1997. Available at http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/53bdbf1c5aa1083986256c690074ebab/$FILE/150-5200-33.pdf.

Hileman, J., D. Ortiz, J. Bartis, H. Wong, P. Donohoo, M. Weiss, and I. Waitz. Near Term Feasibility of Alternative Jet Fuel. PARTNER-COE-2009-001. PARTNER Project 28, 2009. Available at http://web.mit.edu/aeroastro/partner/reports/proj17/altfuelfeasrpt.pdf.

Kalnes, T. N., M. M. McCall, and D. R. Shonnard. "Renewable Diesel and Jet-Fuel Production from Fats and Oils." In *Thermochemical Conversion of Biomass to Liquid Fuels and Chemicals,* edited by M. Crocker. London: Royal Society of Chemistry, 2010.

Morser, F., P. Soucacos, J. I. Hileman, P. Donohoo, and S. Webb. *ACRP Report 46: Handbook for Analyzing the Costs and Benefits of Alternative Aviation Turbine Engine Fuels at Airports.* Transportation Research Board of the National Academies, Washington, D.C., 2011.

Shonnard, D. R., L. Williams, and T. N. Kalnes. "*Camelina*-Derived Jet Fuel and Diesel: Sustainable Advanced Biofuels." *Environmental Progress & Sustainable Energy,* Vol. 29, No. 3, 2010.

Sissine, F. Energy Independence and Security Act of 2007: A Summary of Major Provisions. Order Code RL34294. Congressional Research Service, 2007. Available at http://energy.senate.gov/public/_files/RL342941.pdf.

Stratton, R. W., H. M. Wong, and J. I. Hileman. Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels. Project 28 Report, version 1.2. PARTNER 2010. Available at http://web.mit.edu/aeroastro/partner/projects/project28.html.

Taylor, W. *Survey of Sulfur Levels in Commercial Jet Fuel.* Coordinating Research Council, 2009. Available at http://www.crcao.com/reports/recentstudies2009/AV-1-04/CRC%20FinalReportAV-1-04%20-%2002062009.pdf.

6.7 Economic Benefits of Alternative Jet Fuels

Eidman, V. R. "Economic Parameters for Corn Ethanol and Biodiesel Production." *Journal of Agricultural and Applied Economics,* Vol. 39, No. 2, 2007, 345–356.

Flanders, A., A. Luke Morgan, G. Shumaker, and J. McKissick. "Economic Impacts of Ethanol Production in Georgia." Association Annual Meeting, Southern Agricultural Economics, Mobile, AL, 2007.

Hodur, N. M., F. L. Leistritz, and T. Hertsgaard. "Contribution of the North Dakota Agricultural Products Utilization Commission Programs to the State Economy." Staff Paper No. AAE 06006. North Dakota State University Department of Agribusiness and Applied Economics, 2006. Available at http://ageconsearch.umn.edu/handle/23653.

Lewandowski, I., J. M. O. Scurlock, E. Lindvall, and M. Christou. "The Development and Current Status of Perennial Rhizomatous Grasses as Energy Crops in the U.S. and Europe." *Biomass and Bioenergy,* Vol. 25, 2003, 335–361.

Low, S. A., and A. M. Isserman. "Ethanol: Implications for Rural Communities." In *2008 Annual Meeting.* Orlando, FL: Agricultural and Applied Economics Association, 2008.

Peters, D. J. *The Economic Impact of Ethanol Production in Hall County.* RD-2007-05-1. University of Nebraska, Agricultural Economics Department, 2007. Available at http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1064&context=ageconfacpub.

Swenson, D., and L. Eathington. "Determining the Regional Economic Values of Ethanol Production in Iowa Considering Different Levels of Local Investment." Grant BIOE2006-01. Iowa State University Department of Economics, 2006. Available at http://www.econ.iastate.edu/research/webpapers/paper_12687.pdf.

6.8 Possible Economic Benefits of Regulation

California Environmental Protection Agency. Facts About Assembly Bill 32 Global Warming Solutions Act. 2009. Available at http://www.arb.ca.gov/cc/factsheets/ab32factsheet.pdf.

Environmental Protection Agency. Acid Rain Program. 2010. Available at http://www.epa.gov/airmarkets/progsregs/arp/index.html.

Environmental Protection Agency. Clean Air Act. 1990. Available at http://www.epa.gov/air/caa/.

Environmental Protection Agency. *EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond.* Report EPA-420-F-10-007. 2010. Available at http://www.epa.gov/oms/renewablefuels/420f10007.htm.

Environmental Protection Agency. *Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft.* Report EPA420-R-99-013. 1999. Available at http://www.epa.gov/oms/regs/nonroad/aviation/r99013.pdf.

Environmental Protection Agency. NO_x Budget Trading Program. 2010. Available at http://www.epa.gov/airmarkets/progsregs/nox/sip.html.

Environmental Protection Agency. Clean Air Markets. Environmental Protection Agency, 2010. Available at http://www.epa.gov/airmarkets/.

European Commission. Emissions Trading System (EU ETS). 2010. Available at http://ec.europa.eu/clima/policies/ets/index_en.htm.

Federal Aviation Administration. *Air Quality Procedures for Civilian Airports and Air Force Bases.* Report FAA-AEE-97-03. 1997. Available at http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/media/Handbook.pdf.

International Air Transport Association. *IATA Alternative Fuels Report.* IATA 2009 Report on Alternative Fuels. 2009. Available at http://www.iata.org/SiteCollectionDocuments/Documents/IATA2009ReportonAlternativeFuelsonlineversion.pdf.

Regional Greenhouse Gas Initiative, Inc. RGGI, Inc., home page 2011. Available at http://www.rggi.org/rggi.

Sissine, F. Energy Independence and Security Act of 2007: A Summary of Major Provisions. Order Code RL34294. Congressional Research Service, 2007. Available at http://energy.senate.gov/public/_files/RL342941.pdf.

6.9 Financial Considerations

U.S. Department of Agriculture Rural Business-Cooperative Service. Biorefinery Assistance Guaranteed Loans. 7 CFR Parts 4279, 4287 and 4288. 2010. Available at http://www.rurdev.usda.gov/rbs/busp/9003%20ProposedRule%2004-16-2010.pdf.

U.S. Department of Agriculture, Iowa Rural Development. Business and Cooperative Programs. 2010. Available at http://www.rurdev.usda.gov/ia/rbs.html.

U.S. Department of Agriculture. Section 9003—Biorefinery Assistance Program, Biorefinery Assistance Loan Guarantees. 2010. Available at http://www.rurdev.usda.gov/rbs/busp/baplg9003.htm.

6.10 Regulatory Considerations

Air Transport Association. "ATA/DESC Announce Strategic Alliance for Alternative Aviation Fuels." 2010. Available at http://www.airlines.org/News/Releases/Pages/news_3-19-10.aspx.

Air Transport Association. Commercial Aviation Alternative Fuels: The ATA Commitment. 2010. Available at http://www.airlines.org/Environment/AlternativeFuels/Pages/CommercialAviationAlternativeFuelsTheATACommitment.aspx.

Airports Council International–North America. Sustainable Aviation. 2010. Available at http://www.aci-na.org/sustainability/index.html.

American Fuels. Biodiesel Tax Credit Approved. 2010. Available at http://americanfuels.blogspot.com/2010/07/biodiesel-tax-credit-approved.html.

Congressional Research Service. "Department of Defense Fuel Spending, Supply, Acquisition, and Policy." 2009. Available at http://www.fas.org/sgp/crs/natsec/R40459.pdf.

Department of Ecology. "SEPA Guide for Project Applicants." 2010. Available at http://www.ecy.wa.gov/programs/sea/sepa/apguide/apguide1.htm.

Environmental Protection Agency. "Obama Announces Steps to Boost Biofuels, Clean Coal." *News Releases Issued by the Office of Air and Radiation,* 2010.

European Commission. Establishing a Scheme for Greenhouse Gas Emission Allowance Trading Within the Community and Amending Council Directive 96/61/EC. Directive 2003/87/EC. 2003. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:275:0032:0046:en:pdf.

Federal Aviation Administration. *Air Quality Procedures for Civilian Airports and Air Force Bases.* Report FAA-AEE-97-03. 1997. Available at http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/media/Handbook.pdf.

Federal Aviation Administration. Aircraft Fuel Storage, Handling, and Dispensing on Airports. AC 150/5230-4A. 2004. Available at http://www.faa.gov/documentLibrary/media/advisory_circular/150-5230-4A/150_5230_4a.pdf.

Federal Aviation Administration. Airport Design. AC 150/5300-13. 1989. Available at http://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5300_13.pdf.

Federal Aviation Administration. Airport Grant Assurance Compliance Certification. Form ANM620agaacc. 2005. Available at http://www.faa.gov/airports/northwest_mountain/airports_resources/forms/media/compliance/compliance_certification_form.doc.

Federal Aviation Administration. Airport Sponsor Assurances. 2005. Available at http://www.faa.gov/airports/aip/grant_assurances/media/airport_sponsor_assurances.pdf.

Federal Aviation Administration. Approval of Propulsion Fuels and Lubricating Oils. AC 20-24C. 2010. Available at http://www.faa.gov/AIRCRAFT/DRAFT_DOCS/media/DraftAC20_24C.doc.

Federal Aviation Administration. Environmental Impacts: Policies and Procedures. Order 1050.1E. 2004. Available at http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgOrders.nsf/78684301 3bf2d049852569810075c599/9552db552fd4495b862570660068adb1/$FILE/Order1050-1E.pdf.

Federal Aviation Administration. *FAA Airport Compliance Manual.* Order 5190.6B. 2009. Available at http://www.faa.gov/airports/resources/publications/orders/compliance_5190_6/media/5190_6b_appR.pdf.

Federal Aviation Administration. Federal Aviation Regulations, Part 77, Objections Affecting Navigable Airspace. 1993. Available at https://oeaaa.faa.gov/oeaaa/external/content/FAR_Part77.pdf.

Federal Aviation Administration. Land Use Compatibility and Airports. 2001. Available at http://www.faa.gov/about/office_org/headquarters_offices/aep/planning_toolkit/media/III.B.pdf.

Federal Aviation Administration. Minimum Standards for Commercial Aeronautical Activity. AC 150/5190-7. 2006. Available at http://www.faa.gov/documentLibrary/media/advisory_circular/150-5190-7/150_5190_7.pdf.

Federal Aviation Administration. National Environmental Policy Act (NEPA) Implementing Instructions for Airport Projects. Order 5050.4B. 2006. Available at http://www.faa.gov/airports/resources/publications/orders/environmental_5050_4/.

Federal Aviation Administration. Revenue Producing Facility Policy. 2010. Available at http://www.faa.gov/airports/central/aip/revenue_producers/.

Finnessy, T. "The Story on Title III." 2006 Wire Development Workshop, St. Petersburg, FL, 2006. http://theeestory.com/files/finnessy.pdf.

Georgia Centers of Innovation. http://www.georgiainnovation.org/.

Governor's Office of Regulatory Assistance. "Biodiesel Facility Commercial Environmental Planning Fact Sheet." 2010. Available at http://www.ora.wa.gov/documents/ENV_008_08.pdf.

International Air Transport Association. Fact Sheet: Carbon-Neutral Growth. 2010. Available at http://www.iata.org/pressroom/facts_figures/fact_sheets/Pages/carbon-neutral.aspx.

Neumann, A., and C. von Hirschhausen. "Long-Term Contracts for Natural Gas: An Empirical Analysis." 9th ISNIE Conference. Barcelona, Spain: International Society for New Institutional Economics, 2005.

Ohio Soybean Growers Association. http://associationdatabase.com/aws/OHSOY/pt/sp/Home_Page.

Partnership for AiR Transportation Noise and Emissions Research. Project 20-Emissions Characteristics of Alternative Aviation Fuels. 2010. Available at http://web.mit.edu/aeroastro/partner/projects/project20.html.

Partnership for AiR Transportation Noise and Emissions Research. Project 27-Environmental Cost-Benefit Analysis of Ultra Low Sulfur Jet Fuels. 2010. Available at http://web.mit.edu/aeroastro/partner/projects/project27.html.

Partnership for AiR Transportation Noise and Emissions Research. Project 28-Environmental Cost-Benefit Analysis of Alternative Jet Fuels. 2010. Available at http://web.mit.edu/aeroastro/partner/projects/project28.html.

Roundtable on Sustainable Biofuels. http://rsb.epfl.ch/.

U.S. Department of Agriculture. USDA Meets President Obama's 30-Day Biofuels Directive to Help Meet Country's Energy Needs. 2009. Available at http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=2009/06/0201.xml.

6.11 Publicly Announced Alternative Jet Fuel Projects

Air Transport Association. "Additional Details for Airlines Alternative Fuel Development News Release." 2009. Available at http://airlines.org/News/Releases/Pages/news_12-15-09b.aspx.

Air Transport Association. "Airlines Sign First-of-Its-Kind Ongoing Supply Agreement with Rentech and ASIG for Renewable Synthetic Diesel Fuel to Be Used in Lax Ground Service Equipment." 2009. Available at http://www.airlines.org/News/Releases/Pages/news_8-18-09.aspx.

Heim, K. "Seattle Startup Gets 14 Airlines to Sign on to Biofuel Agreement." *The Seattle Times,* 2009.

Rentech. Natchez Project. 2010. Available at http://www.rentechinc.com/natchez.php.

Solena Group. BA and Solena Plan Waste-to-Biofuel Plant. (2010). Available at http://www.solenagroup.com/pdffiles/100726-Farnborough_Press_Notice_July_2010.pdf.

Appendices: Primer on Alternative Jet Fuels

APPENDIX A

Introduction

This primer on alternative jet fuels presents a review and synthesis of available relevant information on alternative jet fuels and their adoption for use in the airport setting. The objective is to create a concise and comprehensive guide on the key aspects of alternative fuels that will affect airport application, thus providing a helpful reference guide to the airport manager and other stakeholders along the supply chain of alternative fuels. Each major topic is contained in a separate appendix.

This primer provides a more detailed discussion of many of the topics contained in Sections 1 through 5 of the handbook that, for space and readability reasons, were not included in the handbook body. In order to make it a useful reference document and consistent with the handbook, this primer repeats some of the information in the handbook.

APPENDIX B

Certification and Drop-In Capability of Alternative Jet Fuels

In considering alternative fuels for aviation use, an initial barrier that must be considered is that the fuel must meet the requirements for use in aircraft. The specifications for jet fuel in the United States and around the world are established by standard-setting organizations such as ASTM International (www.astm.org) and the United Kingdom's Ministry of Defence Standard 91-91 (www.dstan.mod.uk). The FAA refers manufacturers and operators of aircraft to these standards in Aviation Circulars. The latest AC to refer to alternative jet fuels is 20-24C (FAA 2010a). Aviation equipment manufacturers have also adopted these organizations' standards.

ASTM standard D1655 defines the specifications for conventional fuels for commercial use, such as Jet A and Jet A1. ASTM has also issued standards for all jet fuels from nonpetroleum sources under ASTM D7566. Fuels complying with ASTM D7566 are approved for blends of up to 50% synthetic fuel processes, with the remaining 50% derived from approved Jet A1 fuels.

There is no formal definition of or standard for drop-in alternative jet fuels. Nevertheless, an informal definition for a drop-in fuel is one that is fully interchangeable with those fuels complying with ASTM D1655. This interchangeability must be possible throughout the entire product life cycle—from refinery to aircraft. This includes the intermediary distribution steps: pipelines, tank farms, and fuel trucks.

Annexes of ASTM D7566 enable the approval of individual process types. The initial version of ASTM D7566 provides criteria for the production, distribution, and use of aviation turbine engine fuel produced from coal, natural gas or biomass using the Fischer-Tropsch process (see Section D.1). However, the standard is structured to accommodate other future types of synthetic fuels produced from nonconventional feedstocks and processes as they are developed. These new fuel types can be added to ASTM D7566 in annexes after they are qualified. For example, hydrotreated renewable jet or HEFA (see Section D.2) is expected to be qualified for aviation use soon.

Jet fuel made from coal using the Fischer-Tropsch process has been in daily use for scheduled airline service in South Africa for more than 20 years. The South African energy and chemical company Sasol has produced SPK and other chemicals from locally sourced coal using its proprietary version of the Fischer-Tropsch process. When blended up to 50% with conventional jet fuel, Sasol's SPK was approved for use as commercial jet fuel under the U.K.'s DEFSTAN 91-91 in 1998. Since 1999, this jet fuel blend has been used successfully by commercial airlines in aircraft refueled at South African airports, and since then South African Airlines has experienced no fuel-related problems (Roets 2009), including air worthiness, safety, maintenance, or storage and handling in bulk storage facilities (Moses 2008). Indeed, in 2008, DEFSTAN 91-91 approved Sasol's unblended synthetic jet fuel as Jet A-1 fuel, for commercial use in all types of turbine aircraft (Sasol 2011).

Furthermore, there have been numerous examples of flight tests by commercial and military aircraft using alternative jet fuels made with different technologies and feedstocks. A summary of flight demonstrations in commercial aircraft is shown in Table 15. The flight

tests showed no significant difference in the performance of the alternative jet fuel compared to conventional jet fuel.

Furthermore, researchers at the FAA, Department of Defense, and private institutions are pursuing three other processes for approval in 2013–2014. As of this writing, these processes are known as fermentation renewable jet (FRJ), catalytic renewable jet (CRJ), and pyrolysis renewable jet (PRJ) (see Section D.4).

Table 15. Alternative jet fuel flight demonstrations in commercial aircraft.

Date	Airline or Other Sponsor	Aircraft	Engine Maker	Fuel Producer	Feedstock	Technology	Source
Feb 2008	Airbus	A380	Rolls-Royce	Shell	Natural gas	Fischer-Tropsch	Airbus 2011
Dec 2008	Air New Zealand	B747-300	Rolls-Royce	UOP	*Jatropha*	HEFA	Warwick 2009
Jan 2009	Continental	B737-800	GE/CFMI	UOP	*Jatropha*, algae	HEFA	DOE 2009
Jan 2009	Japan Airlines	B747-300	Pratt & Whitney	UOP	*Camelina*, *Jatropha*, algae	HEFA	Mecham 2008
Oct 2009	Qatar	A340-600	Rolls-Royce	Shell	Natural gas	Fischer-Tropsch	Qatar Airways 2011
Nov 2009	KLM	B747-400	GE	UOP	*Camelina*	HEFA	North Sea Group 2011
Apr 2010	United	A319	IAE	Rentech	Natural gas	Fischer-Tropsch	Kuhn 2009
Nov 2010	TAM	A320	CFMI	UOP	*Jatropha*	HEFA	Karp 2010
Apr 2011	InterJet (Mexico)	A320	CFMI	UOP	*Jatropha*	HEFA	Gross 2011
June 2011	Honeywell	G450	Rolls-Royce	UOP	*Camelina*	HEFA	Chatzis 2011
June 2011	Boeing	B747-8	GE	UOP	*Camelina*	HEFA	Lane 2011
July 2011	Lufthansa	A321	CFMI	Neste Oil	Palm oil, rapeseed, animal fats	HEFA	Reals 2011
July 2011	KLM	B737-800	CFMI	Dynamic Fuels	Used cooking oil	HEFA	KLM 2011
July 2011	Finnair	A319	CFMI	SkyNRG	Used cooking oil	HEFA	Mroue 2011
Aug 2011	Aeromexico	B777-200	GE	ASA	*Jatropha*	HEFA	Aeromexico 2011
Sept 2011*	Thomson Airways	B757	Rolls-Royce	SkyNRG	Used cooking oil	HEFA	Thompson 2011
2012*	Porter Airlines	Bombardier Q400	PWC	UOP	*Camelina*	HEFA	Bombardier 2010
2012*	Azul	Embraer	GE	Amyris	Sugarcane	FRJ	Advanced Biofuels 2009
2013*	Air China	B747-400	Pratt & Whitney	UOP	*Jatropha*	HEFA	Stanway 2010

*Announced as of Aug 31, 2011

APPENDIX C

Feedstocks for Producing Alternative Jet Fuels

The two primary sources of feedstock for alternative fuels are fossil fuels and bio-derived feedstocks. Fossil fuel feedstocks include coal and natural gas. Bio-derived feedstocks include plant oils, animal fats, crop residues, woody biomass, municipal solid waste, and other organic material. Each has relative strengths and weaknesses for the production of alternative jet fuel. Biofuels derived from starch, sugar, animal fats or vegetable oils are generally considered first-generation biofuels. Biodiesel, ethanol, and biogas are commonly recognized as first-generation biofuels that use established technologies. Fuels produced from biomass are referred to as second-generation biofuels and are considered to be more sustainable in the long term with a potentially smaller carbon footprint. Second-generation biofuels are not produced commercially at this time because numerous technical challenges remain (Naik et al. 2010). The following is a discussion of each potential alternative jet fuel feedstock and the most important considerations for each.

C.1 Fossil Fuels

Coal and natural gas can be used to make alternative jet fuel with the FT process (see Section D.1) and are ideal feedstock for FT processes for a variety of reasons. Large FT plants are the most economical, and require ample supplies of feedstock to run at optimal capacity. Because of availability, established and cost effective transportation systems, and developed markets, coal and natural gas can support production at commercial scales.

C.1.1 Sources and Availability

Ample supplies of coal and natural gas at low per-unit costs support large rates of extraction for sustained periods of time. Costs and methods for coal and natural gas exploration and extraction are well known, and large untapped deposits of both coal and natural gas exist in the United States and elsewhere.

C.1.2 Economics and Logistics

Coal and natural gas have well-developed markets, supply chains, pricing mechanisms, and risk management tools. From a transportation and logistical perspective, the required rail and pipeline infrastructure in the United States is well developed and is more cost effective than truck transportation. Coal is typically transported by rail, and natural gas is normally shipped by pipeline (EIA 2010). To take advantage of these cost-effective transportation modes, however, an alternative fuel processing facility would need to be located in proximity to existing infrastructure. Construction of new rail lines or pipelines is very expensive and time consuming and would likely compromise the viability of any alternative fuel project. For information of where

existing rail and pipeline infrastructure is located, project developers can consult the National Atlas of the United States (http://www.nationalatlas.gov/natlas/Natlasstart.asp) and the U.S. Department of Transportation's National Pipeline Mapping System (http://www.npms.phmsa.dot.gov/), respectively.

Transportation costs for coal and natural gas have been decreasing over the last few decades. The average utility contract cost of coal transportation has decreased sharply from \$17/ton in 1980 to about \$12/ton in 2005, although the share of transportation as a percentage of delivered price has increased from about 22% to 35% in the same period (Bowen and Irwin 2007). In the case of natural gas, transportation and distribution costs constitute about half of the cost of the product for residential consumers, even as the price of the commodity has fluctuated over time (Natural Gas Supply Association 2010). The average duration of utility coal contracts is significantly longer than for agricultural commodities, although there has been a decrease from 22 years in the late 1970s to about 14 years in the late 1990s (Bowen and Irwin 2007). Similar to coal, the average contract length for natural gas has decreased from 20 to 25 years to about 8 to 15 years (Neumann and von Hirschhausen 2005). Most agricultural commodities are contracted on an annual basis (MacDonald and Korb 2011). The relevance of long contracts for feedstocks is that they give processors a better estimate of future costs, which helps in the financial planning. Year-to-year contracts common in agricultural commodities do not offer this advantage for long-term planning.

C.1.3 Environmental Considerations

The life-cycle GHG footprint of alternative jet fuels from other fossil fuels can be two to three times that of conventional jet fuel (see Box 2). Alternative jet fuel produced through the FT process from natural gas can have a GHG footprint approximately 116% that of conventional jet fuel, while alternative jet fuel from coal can have a GHG footprint 230% that of conventional jet fuel (Stratton, Wong, and Hileman 2010). Carbon capture and the use of biomass in the

Box 2. Brief introduction to life-cycle greenhouse gas analysis.

Life-cycle GHG analysis estimates the amount of greenhouse gases (e.g., CO_2) released in the full life cycle of an alternative fuel (see Section 5.1 for a more complete discussion). This includes emissions from the production, distribution, and combustion of an alternative fuel including extraction, inputs to production such as tillage, planting and harvesting biomass feedstocks, processing and conversion, transportation, and storage. It is a cradle-to-grave estimate of all GHG emissions from the production of the fuel.

A key concept in life-cycle GHG analysis is land-use change. Land-use change can lead to indirect GHG emissions. For example, increased demand for feedstocks that compete for land with the existing food and feed production chain (e.g., corn, soybeans) may lead to conversion of unused land, such as grassland or forests, to agriculture production. This can result in an increase in CO_2 emissions that would be included in the life-cycle GHG analysis. Thus, LCA results can show a significant increase in GHG emissions for alternative fuels made from renewable feedstocks because of indirect land-use change. Inclusion of indirect land-use changes in life-cycle analysis is currently a controversial and politically charged debate.

feedstock stream can reduce the GHG footprint to a fraction of that of conventional jet fuel. For example, the use of CCS can lead to alternative jet fuel from coal having a GHG footprint 111% that of conventional jet fuel. Depending on the assumptions of biomass content and land-use change (see more in Section E.1), alternative jet fuel can have a GHG life-cycle footprint 20% to 60% that of conventional jet fuel (Stratton, Wong, and Hileman 2010). Carbon capture and sequestration technologies are currently under development, and their cost and effectiveness are yet to be determined at a commercial scale.

C.1.4 Advantages

Fossil fuel feedstocks are abundant and available at low cost. They are complementary to the scale and substantial investment necessary to operate FT plants. Both coal and natural gas have well-developed markets and supply chains. Both have been actively traded for many years, so there is ample price history and sophisticated financial instruments, such as futures and options markets, to understand prices and hedge price volatility. Fossil fuel feedstocks, price, and availability are compatible with the large capital investments required to install and operate FT plants.

C.1.5 Disadvantages

Fossil fuels feedstocks may have a potentially unacceptable life-cycle GHG footprint—two to three times that of conventional jet fuel. FT plants tend to be very large and capital intensive, which may deter commercialization efforts, especially in today's more conservative investment atmosphere. In addition, since there are not many commercial-scale examples in operation, it is difficult to evaluate their economics of production.

C.2 Oils and Fats

Plant oils and animal fats can be used as feedstocks for making alternative jet fuels via hydroprocessing (see Section D.2). Biodiesel is the only commercial-scale example of a renewable fuel produced from vegetable oils and other fats. While HEFA and biodiesel are decidedly different products with different applications, the experience of the biodiesel industry illustrates the potential opportunities and challenges associated with the use of vegetable oils and animal fats as feedstock for alternative aviation fuels.

C.2.1 Sources and Availability

Many different plant oils can be used to make alternative jet fuel, including food oils such as soybean, canola, palm, sunflower, and coconut oil and nonfood oils such as *Camelina*, *Jatropha*, algae, and pennycress (Eidman 2007; Paulson and Ginder 2007; Carriquiry and Babcock 2008; IATA 2009; Moser 2009; USDA 2010i). Each has relative strengths and weaknesses. For example, mustard can be grown with relatively fewer production inputs, but yields less oil than other feedstocks such as canola (USDA 2010g; USDA 2010l). Some of these oils are currently produced at commercial or semicommercial scales in the United States. Others have not yet reached such large scales. Research is ongoing to improve the oil content (yields) and other characteristics that are advantageous to alternative jet fuel production. Nonfood oils such as those based on algae, *Jatropha*, pennycress, and *Camelina* are promising potential feedstocks with attractive characteristics (Qiang, Du, and Liu 2008; Moser 2009). They are adaptable, grow very quickly, and have higher oil content than other alternative fuel feedstocks (USDA 2010a). *Jatropha*, an oilseed plant historically grown in tropical areas, has high concentrations of oil and can be grown in poor-

quality soils not suitable for traditional agricultural crops. It may be adaptable in southern regions of the United States (FAO 2009; USDA 2010l). Pennycress, *Camelina*, and other tree oils also are promising potential feedstocks with high oil content that have the potential to be grown without competing for land availability with traditional crops.

Microalgae have been shown to have particularly attractive characteristics. Alga is plant that grows in water and has a remarkable capability of producing large amounts of oil. Of the several types of algae, two of them—cyanobacteria and microalgae—grow in diverse environments, including wastewater and salt water. Microalgae and cyanobacteria produce oil via photosynthesis, in open or closed ponds, or in the dark using nutrients supplied by the growers (DOE 2010). Another remarkable property of algae is that, unlike other plants used for biofuels, they do not compete with food stocks for land and do not consume water.

Some strains of algae have the potential to produce more than 30 times the amount of oil per acre per year than any other plant currently used to produce alternative fuels (Verrengia 2009); see Table 16. However, current production yields are not commercially viable.

Jet fuel derived from algae holds great promise as a second-generation biofuel to satisfy the needs of the aviation industry. However, the technical promise is tempered by concerns about the financial and environmental viability of turning algae into fuel. The primary concern and unresolved issue with algae from open-pond and closed-pond systems is the energy cost and life-cycle carbon impacts of maintaining temperature and extracting water. These leave algae-based fuels as having potentially uncompetitive cost and unacceptable carbon life-cycle footprint outcomes based on currently reported research (Stratton, Wong, and Hileman 2010). The process of creating jet fuel from algae is still very much in the research stage. As a result, it is difficult to discuss economic and production issues in detail.

Animal fats (tallow), frying oils, and greases may also be used to produce alternative jet fuel. Expanding the use of frying oils and greases may represent a potential alternative fuel feedstock. Generally considered waste products, these materials are more economically attractive than refined vegetable oils. However, quality control problems with this feedstock may produce unacceptable fuels and require additional processing (Eidman 2007; Canakci and Sanli 2008; USDA 2010q). These materials are also in limited supply, thereby constraining their use as a fuel on a commercial scale (Knothe 2010). Tallow, a rendered form of animal fat that is high in triglycerides, can also be used in the HJR processes to make alternative jet fuel (Bauen et al. 2009). Tallow is used in a wide variety of products, including margarine, cooking oil, soap, candles, and lubricants (CRB 2008). Availability of tallow is most likely to remain steady as it is a by-product of the meat processing industry.

Table 16. Estimates of oil yield potential for different feedstocks (DOE 2010).

Feedstock	Oil Yield (gallons/acre/year)
Soybean	48
Camelina	62
Sunflower	102
Jatropha	202
Oil palm	635
Algae	1,000–6,500

C.2.2 Economics and Logistics

As is the case with the production of biodiesel made from oils and fats, feedstock cost is expected to be the largest cost component in the production of alternative jet fuel from plant oils. Some plant oils that could potentially support commercial-scale production of alternative jet fuel, such as soybean oil, are already expensive to produce. In addition, because soybean and other plant oils are also used for human and animal consumption and in the production of biodiesel, competition for this feedstock is likely to keep prices high. Currently, the high cost of feedstock is limiting the further development and commercialization of the biodiesel industry (Al-Zuhair 2007; Ng, Ng, and Gan 2009). Currently, biodiesel cannot compete with conventional diesel and likely will not in the foreseeable future without some form of public policy incentive (Al-Zuhair 2007; Carriquiry and Babcock 2008; Ng, Ng, and Gan 2009). Aviation alternative fuels such as HEFA production would likely face similar challenges. Therefore, there is great interest in alternative oilseed feedstocks such as *Jatropha,* pennycress, and *Camelina* that can be produced at a lower cost.

Soybean oil and other oilseed feedstocks have well-developed markets, available risk management tools, and well-developed supply chains. Markets, pricing mechanisms, risk management tools, and contract and supply chain considerations would all have to be developed for algae, *Jatropha,* and other feedstocks not currently produced at a commercial scale. Markets, transportation, and infrastructure considerations for oilseeds not currently produced at a commercial scale, such as mustard or *Camelina* (both of which have characteristics similar to traditional oilseeds), would be expected to develop and function similarly to existing commodity markets and systems (Olson, pers. comm.).

Transportation and logistical considerations for bio-based feedstocks depend greatly on the type of feedstock. For traditional oilseeds such as soybean and canola, project developers can take advantage of existing transportation and logistics infrastructure. Currently, agriculture commodities are largely transported by rail and truck. For new types of oilseeds, such as *Camelina,* it is likely that the existing truck and rail transportation and logistics systems will be sufficient. Like coal and natural gas feedstocks, the production facility would have to be located within reach of the existing infrastructure to enjoy the full benefits. If production of oilseeds for biofuels were to increase substantially, additional crushing and refining capacity would need to be developed. As is the case with current crushing and refining facilities, additional capacity for new oilseeds would need to be located in proximity to the commodity production area and existing transportation infrastructure to minimize capital costs.

Supplies of tallow and municipal solid waste are likely to be constrained by the cost of transportation and other logistics. Tallow is typically stored in heated tanks and must be kept at a minimum of 65°C to thwart the growth of bacteria and enzymatic activity (Food Science Australia 1997). Transportation costs can be expensive due to the need to maintain these specific ambient conditions. These materials are also in limited supply, thereby constraining their use as a fuel on a commercial scale (Knothe 2010).

C.2.3 Environmental Considerations

Alternative jet fuels from plant oils and fats may have a lower life-cycle GHG footprint compared to conventional jet fuel; however, the life-cycle GHG footprint of alternative jet fuels from plant oils is very dependent on land use. If the plant oil is grown on existing cropland, the land-use change impact may be limited; however, if forest or grassland needs to be cleared to meet the demand for plant oil, the land-use impact would be significant. Plant oils that can grow in fallow or on marginal lands, such as *Jatropha* and *Camelina,* can mitigate some of these concerns.

C.2.4 Advantages

Some plant oils are available in commercial quantities and have developed markets, supply chains, and transportation systems. Some alternative feedstocks have great potential. Some strains of algae have the potential to produce more than 30 times the amount of oil per acre per year than any other plant currently used to produce alternative fuels.

C.2.5 Disadvantages

Oil-based alternative jet fuel feedstocks will likely have high costs, similar to biodiesel. Currently, feedstock costs make up 80% or more of the cost of HEFA. Improving the productivity of oil plants is critical to achieving competitive costs for alternative jet fuel. USDA has programs in place to improve yields over time, much like the manner in which food crop yields have improved over time. Current production yields for algae are not commercially viable and are still in the research stage. Algae-based fuels may not be cost competitive with conventional fuels and may have an unacceptable carbon life-cycle footprint.

Tallow-based oils enjoy a steady supply, but storage and transportation issues may constrain their use as a feedstock. Furthermore, their limited supply may constrain their use on a large-scale commercial basis.

C.3 Biomass Feedstocks

Biomass feedstocks can consist of any biomass source but are generally divided into three categories: energy crops, agricultural residues, and woody biomass. The potential supply of biomass is substantial, although there are considerable constraints related to its bulk. Biomass can be used with the FT process to produce alternative jet fuel.

C.3.1 Sources and Availability

Energy crops are grown specifically for biofuels production, including alternative jet fuel. In order to prevent competition with current agricultural production activities and in an attempt to reduce their production costs, energy crops will likely be grown on land that is currently seen as marginal for traditional crop production. In 1984, the U.S. DOE funded the Herbaceous Energy Crops Program (HECP). After evaluation of 35 energy crops of which 18 were perennial grasses, the DOE selected switchgrass as the native grass with the greatest potential as an energy crop. In 1991, the DOE's Bioenergy Feedstock Development Program (BFDP), which evolved from the HECP, continued research on switchgrass and identified the following advantages as an energy crop: (1) capacity for high yields on poor-quality sites not suitable for conventional crops, (2) adaptability to a variety of soils and climatic conditions with relatively low input requirements, (3) easily integrated into conventional farming operations, (4) adaptable to once-per-year harvesting, and (5) suitable for harvest with conventional hay equipment (Lewandowski et al. 2003; USDA 2010o).

In recent years, researchers have focused attention on several other potential energy crops, including *Miscanthus* (Lewandowski et al. 2003; Busby et al. 2007; Khanna, Dhungana, and Clifford-Brown 2008; USDA 2010j), energy cane (Mark, Darby, and Salassi 2010), wheatgrass, and bluestem (Nyren et al. 2007). Results to date indicate that some alternative crops may outperform switchgrass in some locations. Energy crop production will likely vary regionally.

Agricultural residues such as corn stover and wheat straw are other promising sources of biomass feedstock for alternative jet fuel production. Corn stover includes the leaves and stalks of

the corn plant; wheat straw is the unharvested wheat stalk. These products account for most of the agricultural residues with feedstock potential (Maung and McCarl 2008). Agricultural residues have an advantage over energy crops because they are not dedicated to energy production. Corn and wheat are already under production for the grain produced by the plants, and therefore the production cost of the stover and straw is already covered (Gallagher 2006). However, a farmer will likely require payment. It is important to keep in mind that not all of a field's crop residues can be collected. Crop residues have important soil quality benefits, namely nutrient cycling and moisture retention. While potential supplies are substantial, research is ongoing to understand how much crop residue biomass can be removed without detrimental impacts.

Woody biomass and by-products are also potential feedstocks. The lumber, mill, pulp, and paper industries have long used by-products of mill activities as a source of energy. Most available supplies are currently consumed by the industry (Rousseau 2010). More recently, pyrolysis technology has been developed that uses woody biomass as a feedstock for liquid fuels; however, the conversion process is not yet competitive with petroleum fuels (Rousseau 2010). Milbrandt (2005) estimates the quantities of woody biomass potentially available for biofuels production. Recent declines in these industries, however, are driving down the costs of woody biomass and spurring interest in its use for producing alternative jet fuel (Lane 2010).

The type and availability of biomass varies considerably based on geographic region. A list of some existing and potential feedstocks by region across the United States can be found at the USDA National Renewable Energy Lab's interactive Biofuels Atlas (http://maps.nrel.gov/biomass and http://www.nrel.gov/gis/mapsearch/index.html). The "Billion-ton Report" also details potential biomass resources (Perlack et al. 2005).

C.3.2 Economics and Logistics

Energy crops would need to be grown on marginal lands not appropriate for traditional agriculture production in order to keep feedstock cost low. Absent production on marginal lands, energy crops will have to compete for land use with current agriculture production activities and provide a return to producers at least equal to current production. Agriculture residues such as corn stover and wheat straw have an economic advantage over dedicated energy crops because they are by-products of corn and wheat production. Even though the production costs of agricultural residues are already covered by existing revenues, producers will likely require additional incentives as compensation for harvest, collection, and transportation costs. Furthermore, agricultural residues have soil quality benefits such as nutrient cycling and moisture retention; therefore, not all agriculture residues could be collected.

There are numerous challenges associated with the use of dedicated energy crops and agriculture crop residues as alternative fuel feedstock. Because there are no widely established markets or infrastructure for these types of feedstocks, contracting and supply-chain considerations need to be resolved before producers would be willing to supply a dedicated energy crop or agriculture residue. Most energy crops take more than one year to establish, and it is likely there would not be an alternate market for energy crops during that time. Therefore, a producer may require an upfront payment and/or a multiyear contract before producing an energy crop (Leistritz et al. 2009). Furthermore, producers would need to receive a rate of return on energy crops at least equal to what they could expect to receive from current production activities. The Biomass Crop Assistance program created in the 2008 Farm Bill attempts to address these issues by providing payment to farmers for establishing energy crops (USDA 2010b).

Harvest of energy crops and agricultural residues adds another dimension of complexity to the logistics of these feedstocks. On the one hand, biomass harvest is seasonal and the timing of the harvest may vary depending on crop and region of the county. On the other hand, alterna-

tive fuel processing facilities need feedstock year round in order to maximize utilization of capital assets. Therefore, processing facilities will require storage of large quantities of feedstock (DOE 2003; Leistritz et al. 2009; Rentizelas, Tolis, and Tatsiopoulos 2009; Inman et al. 2010). Furthermore, the economics of transporting these bulky and not very dense materials limits their collection to a maximum distance of about 50 miles from the processing facilities (Aden et al. 2002; Hess, Wright, and Kenney 2007; Mapemba et al. 2007; Lazarus 2008; Leistritz et al. 2009). Densification techniques such as grinding, pelleting, and cubing have been examined as ways to improve the bulk density of biomass to improve storage and transportation logistics; however, densification adds to the cost of biomass (DOE 2003; Sokhansanj and Turhollow 2004; Carolan, Joshi, and Dale 2007; Kumar and Sokhansanj 2007; Brechbill and Tyner 2008; Petrolia 2008).

The huge quantities of biomass required to support commercial-scale operations make transportation and logistical issues very challenging. Densification and pretreatment techniques to address these issues are being studied. Woody biomass not currently utilized for other products and processes, such as harvest residues, faces logistical challenges similar to crop residues and energy crops due to low bulk density.

C.3.3 Environmental Considerations

Assumptions about life-cycle analysis and land use can have a bearing on the life-cycle GHG footprint of alternative jet fuels made from biomass feedstocks. In order to prevent competing uses for land, dedicated energy crops will need to be grown on land that is marginal for traditional agriculture. Assuming no changes in land use, the life-cycle GHG footprint of alternative jet fuels from biomass can be less than that of conventional jet fuels (see Section E.1).

C.3.4 Advantages

Energy crops may be able to grow on land not suitable for traditional agriculture, are adaptable to various soils and climates, and integrate well with conventional agriculture. The use of marginal land for energy crops eliminates the competition for land with traditional agriculture commodity production, reduces production costs, and avoids food-versus-fuel concerns (see Box 3 for more information). Agriculture residues may be available in sufficient quantities to potentially support a commercial conversion facility. Corn stover and wheat straw have the greatest potential as low-cost, first-generation biomass feedstocks.

C.3.5 Disadvantages

Harvest, storage, transportation, and logistical challenges are major impediments. The low bulk density and the sheer volume of biomass needed to support a commercial conversion facility represent significant hurdles to commercialization. In addition market, supply chain, contracting, and other producer issues would also need to be resolved before commercialization efforts would be feasible.

C.4 Municipal Solid Waste

C.4.1 Sources and Availability

MSW includes a wide array of discarded materials such as residential and commercial garbage, plastics, textiles, wood, yard trimmings, and food scraps. In some areas, MSW can also include non-solid materials such as sludge from wastewater treatment plants. Given the diversity of materials involved with MSW, different technologies can be used to produce alternative fuels (Williams

Box 3. Questions regarding food versus fuel.

The "food-versus-fuel" debate arises from questions related to the use of agricultural food commodities for the production of alternative fuels. The debate stems from a spike in animal feed costs and food prices in 2008 and the rapid development and expansion of the corn ethanol industry. Currently, nearly 35% of the domestic corn crop is used for ethanol production (USDA 2011). Some people fear that the use of corn as a feedstock for alternative fuel production will lead to higher food prices and perhaps even compromise food supplies (Brown 2007; Sagar and Kartha 2007; Vidal 2010). Others argue that the rapid increase in food prices in 2008 was the result of high energy costs, not corn ethanol production (Baffes and Haniotis 2010). Others contend that biofuels can be produced without affecting food production (Dale et al. 2010). The issue has become politically charged, and there is little consensus of the role of alternative fuel production on food production and prices. Second-generation feedstocks that are not used for food or animal feed and that do not have any indirect land-use effects (see Box 1) would in theory eliminate any potential food-versus-fuel debate. Examples of potential second-generation feedstocks are agricultural residues such as wheat straw and corn stover, dedicated energy crops such as switchgrass, woody biomass, municipal solid waste, alternative oilseed feedstocks such algae and *Jatropha*, and nonfood oilseeds such as mustard seed and *Camelina*. However, in order for second-generation feedstocks, with the exception of agricultural crop residues, to have no impact on food or feed production, they would have to be cultivated on land not currently used or suitable for traditional agriculture production.

2007). For example, organic material such as food residues and yard clippings can be combined with FT processes to produce liquid fuels. Vegetable oils and other greases can be used with transesterification or hydrogenation processes to produce biodiesel or alternative jet fuel (Wiltsee 1998; IATA 2009).

C.4.2 Economics and Logistics

Once recyclables are removed, waste-to-energy providers and landfills compete for the remaining MSW. Depending on the locality, MSW generators may pay for its disposal. In some instances, however, depending on the market structure and scarcity value of the waste, MSW generators may receive payment for access to their waste. Because of MSW's bulk, an alternative jet fuel processing plant would need to be sited close to existing waste flows. MSW may need to be preprocessed prior to conversion into feedstock. While the preprocessing technology exists, it can add cost to the entire process.

Use of municipal waste as a feedstock provides waste producers with economic benefits that could include reduction of tipping and transportation costs, especially in locations where landfills are fully depleted and where significant cost and energy resources are used to transport waste to remote locations. Broader community benefits could include reduction of landfills and the methane they produce (Brandes 2007) and potential reduction of greenhouse gases (Shi, Koh, and Tan 2009).

The diverse nature of municipal waste necessarily involves diverse supply chains for different types of waste. In general, however, it is expected that project developers interested in using

municipal waste as feedstock will have to work within the established transportation and logistics infrastructure to minimize cost.

C.4.3 Environmental Considerations

Environmental benefits can be tailored to some extent. If an objective is to maximize life-cycle GHG footprint reduction, then plastics and tires can be left out of the feedstock. If an objective is to eliminate the use of landfills, plastics and tires can be included in the feedstock, although this would suboptimize the potential life-cycle GHG reduction.

C.4.4 Advantages

Municipalities may recapture some of their waste-collection costs by selling MSW to refiners. In addition, using MSW can reduce the need for landfills and decrease the associated methane and other greenhouse gasses.

C.4.5 Disadvantages

There are several challenges to using MSW as a feedstock, including consistency and reliability of supply, proximity of waste to the conversion facility, sorting, and preprocessing. The potential perception that an MSW-based alternative jet fuel plant and the accompanying transportation infrastructure degrade the local municipal environment must also be addressed. Furthermore, it needs to be noted that some may perceive use of MSW for fuel as competing with existing recycling programs by diverting waste that would otherwise be recycled to fuel production.

APPENDIX D

Production Technologies for Alternative Jet Fuels

While different technologies exist for the production of alternative fuels, the primary differences are the pathways used to convert materials to fuels. For alternative jet fuels, current technology pathways include (a) hydrotreatment of vegetable oils and/or animal fat to produce bio-synthetic paraffinic kerosene (bio-SPK) (also known as hydroprocessed esters and fatty acids), and (b) FT synthesis of biomass and/or coal and natural gas to produce SPK (see Figure 9). Esterification of vegetable oil or animal fat can be used to produce biodiesel (also known as fatty acid methyl ester, or FAME), but the process is not suitable for alternative jet fuels. Other promising pathways include fermentation, lingo-cellulosic conversion, and pyrolysis of biomass.

In terms of processing technologies, this report focuses on FT and HEFA processes because they are the most advanced and have the highest likelihood of becoming commercially available in the short term. For example, aviation alternative fuels using the FT and HEFA processes have already been certified. In addition, several FT and HEFA projects have been proposed and are in development (see Appendix K).

D.1 Fischer-Tropsch

One process for producing alternative fuels of all kinds, not just jet fuel, is the Fischer-Tropsch process. The FT process uses a chemical reaction to transform a carbon-rich feedstock, such as coal, natural gas, or biomass, into a hydrocarbon fuel. There are variations of the FT process, depending on the feedstock. If the feedstock is coal, the process is known as "coal-to-liquid" or CTL. If the feedstock is natural gas, the process is called "gas-to-liquid," or GTL. If the feedstock is biomass, the process is called "biomass-to-liquid," or BTL. Some FT facilities use a variation of the FT process, operating a biomass-and-gas-to-liquid (BGTL) or coal-and-biomass-to-liquid (CBTL) process.

The typical product distribution of FT production runs is approximately 30% gasoline, 40% jet fuel, 16% diesel, and 14% fuel oil (IATA 2009). Jet fuel produced via this process is often referred to as synthetic paraffinic kerosene. If a higher proportion of concentration of a specific product is desired, such as jet fuel, further processing is required, but it would increase the processing cost and reduce the overall yield of the plant (Hileman et al. 2009).

Carbon capture and sequestration involves capturing the gaseous CO_2 released during a production process and capturing it through storage or by converting it into other carbon compounds that are not released into the atmosphere. CCS will help lower the life-cycle GHG footprint of alternative jet fuels by preventing CO_2 in the processing stage from being released into the atmosphere. Research is being conducted in finding more efficient means of capture, storage, and conversion (Herzog and Golomb 2004). These include algal systems that could potentially convert the gaseous carbon dioxide into carbon-based compounds and carbon-based oils through photosynthetic activity. Other alternatives for CO_2 storage include depleted oil and gas reservoirs and

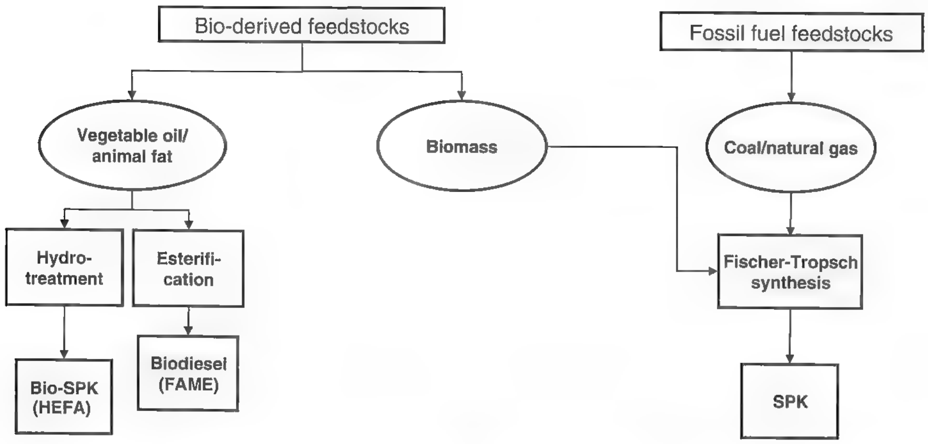

Figure 9. Current technology pathways for the production of alternative fuels. Adapted from Altman (2010).

unminable coal seams. However, available technologies are still very expensive, and the regulatory regime around CCS has not been fully developed. More information on CCS can be obtained from "Carbon Capture and Sequestration Technologies" (MIT 2011) and *Technologies: Carbon Sequestration* (NETL 2011).

D.2 Hydroprocessed Esters and Fatty Acids

HEFA is refined from plant oils (see Figure 10). During the HEFA process, raw oils react with hydrogen (hydrotreatment step), producing the by-products water and carbon dioxide. These by-products remove excess oxygen from the raw oils. Next, the deoxygenated oils again react with hydrogen to undergo hydrocracking—breaking long hydrocarbon chains into smaller ones. During the product separation stage, fuels are extracted by grade. In a typical refining run, the yield for jet fuel is about 10% of the overall output (Bauen et al. 2009). With selective cracking, the yield for jet fuel rises to 50% to 70% of the overall output, but with the same losses in yield and cost performance as with FT.

D.3 Main Characteristics of the Fischer-Tropsch and HEFA Processes

Table 17 lists the main characteristics of the FT and HEFA processes.

A key conclusion from the comparison of HEFA and FT technologies is that FT is suited for large-scale operations in which a large number of products, particularly large quantities of gases and heavy liquids, can be managed in an advantageous manner. This large-scale operation also

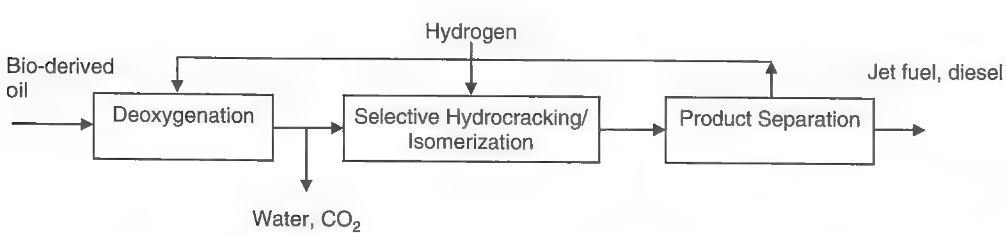

Figure 10. Notional diagram of the HEFA process. Adapted from Anumakonda (2010).

Table 17. Characteristics of the FT and HEFA processes.

Characteristic	Fischer-Tropsch SPK (FT SPK)	Hydroprocessed Renewable Jet (HEFA or bio-SPK)
Feedstock	• Biomass, coal, natural gas.	• Plant oils or animal fats.
Cost of feedstock	• Very low for biomass. • Low for coal. • Medium for natural gas.	• High for commercial plant oils (e.g., soybean) because of high demand. • High for plant oils not currently produced at commercial scales (e.g., *Camelina*) but expected to decrease as scale is achieved. • Medium to low for animal fats.
Cost of feedstock gathering and logistics	• High infrastructure and procurement costs for biomass collection and transport. • Low for natural gas. • Medium for coal.	• Medium to high for extracting plant oils, but low for transporting plant oils with existing infrastructure. • Medium to high for animal fats.
Production costs	• Low marginal cost of production.	• Low to medium marginal cost of production.
Scale	• Very large (300 million GPY minimum, 3 billion GPY typical).	• Medium (7.5 million GPY minimum, 90–150 million GPY typical).
Product quality	• High (meets critical jet fuel properties—like freeze and flash points—defined in the ASTM specification).	• High (meets critical jet fuel properties—like freeze and flash points—defined in the ASTM specification).
By-products	• Large quantities (60%–80%) of by-products: diesel, high molecular waxes, lights, naphtha, LPG.	• Moderate quantities (~20%–30%) of renewable diesel, LPG and naphtha.
Capital requirements	• FT plants are very large—larger than typical crude oil refineries. Small-scale FT plants are being proposed, but typical capital investments are about $500 million for small scale (75 million GPY) and running up to billions of dollars for large scale (750 million GPY).	• Depends on scale. Smallest practical scale is about 7.5 million GPY for about $50 million; larger scale of 70 million GPY for about $250 million.
Plant area or physical footprint	• Typical refinery size footprint is 10 to 15 acres.	• Large-scale refinery is about one-tenth the size of a standard refinery—roughly 1 to 2 acres.
Life-cycle GHG footprint	• Very large for coal gasification without CCS. • Medium for natural gas. • Low for biomass ignoring land-use change. • Medium for biomass including land-use change.	• Low for land-based plant oils ignoring land use. • Very low for sea-based plant oils (e.g., algae). • Medium for plant oils including land-use change.

necessitates adequate supply of large quantities of feedstock, achievable either by a robust feed delivery infrastructure or a concentrated source of feedstock. This is the reason that FT technology has been successful when coal or natural gas has been used as the feedstock, with FT plant sites co-located with or in proximity of large coal mining operations or oil and gas drilling operations. The scattered and distributed nature of biomass availability makes it a challenging problem for BTL plants. Co-feeding some amount of biomass along with coal for CBTL plants is sometimes a partial solution of this problem.

Key challenges for HEFA technology are the restricted supply of plant oils and the resulting high price of these oils for alternative jet fuel production; however, as production of plant oils increases and the supply chains of these feedstocks strengthen, the potential exists for HEFA production to become commercially viable. Incentives and long-term supply contracts may be required to help this industry get started and grow. With time, as the supply chains for bio-

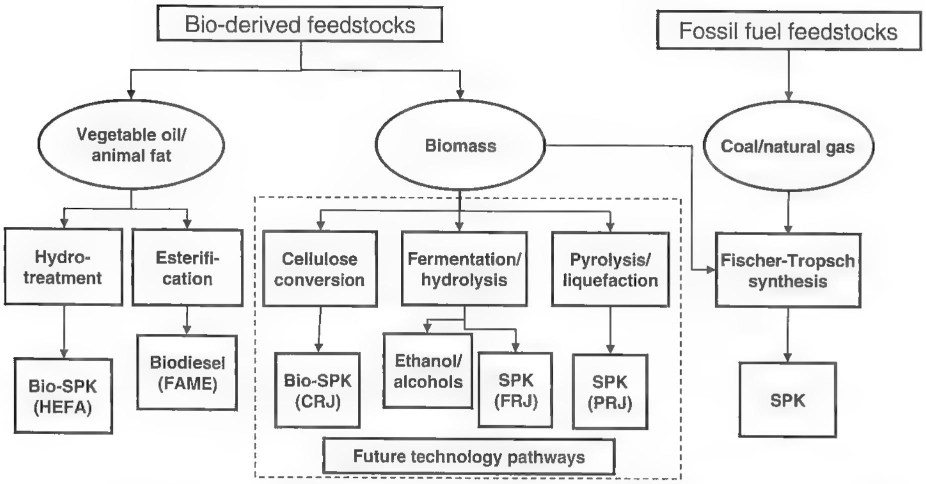

Figure 11. Current and future technology pathways for the production of alternative fuels. Adapted from Altman (2010).

derived feedstocks, including plant oils, biomass, and agricultural residue evolve, it is also conceivable that BTL and CBTL technology may also become economically viable at scale.

D.4 Other Refining Technologies

Other candidate technologies for producing aviation alternative fuels or bio-SPK include cellulosic conversion, fermentation, and pyrolysis. These pathways are currently known as catalytic renewable jet, fermentation renewable jet, and pyrolysis renewable jet, respectively (see Figure 11). These processes produce jet fuel from sugars obtained directly from cane, sorghum, or other sugar-producing feedstocks, or indirectly by extraction from cellulosic feedstocks. These processes are still in the development phase and no short-term commercialization is expected; however, these pathways have the potential to one day offer other options for alternative fuel production. More information about these processes is available from the National Advanced Biofuels Consortium (NABC 2010) and the Advanced Biofuels Association (ABFA 2011). ABFA and its members work closely with CAAFI and its sponsors to align policy and technical matters.

APPENDIX E

Air Quality and Greenhouse Gas Benefits

Alternative jet fuels have two principal potential environmental benefits. First, the overall life-cycle GHG footprint may be lower than that of conventional jet fuel. Second, PM emissions may be lower. Reductions in NO_x have been documented for alternative ground fuels relative to conventional diesel fuel, but there is no current evidence to suggest that the same benefit extends to alternative jet fuels. The following sections discuss the GHG and PM benefits.

E.1 GHG Life-Cycle Benefits

A key benefit often associated with alternative fuels is the potential to reduce total life-cycle GHG emissions (specifically carbon reduction) in comparison with conventional petroleum-based fuels. This potential reduction is quantitatively estimated using the techniques of life-cycle analysis.

Life-cycle analysis as applied to aviation fuel consists of estimating the amounts of various substances produced (or consumed) during the complete process of obtaining and using the fuel. The process is broken down into various stages as the fuel is transformed from its raw form, transported, and used. Depending on the exact feedstocks, processing technologies, and logistics used, the life-cycle carbon footprint of the resulting liquid fuel can be more, equal, or less than the conventional petroleum-based jet fuel. Thus, a life-cycle analysis for each particular alternative fuel is necessary before assigning GHG emissions reduction benefits. Beyond feedstock and process, the analyses will be project specific with variables such as direct and indirect land use in feedstock supply brought into consideration (EPA 1999).

While numerous LCA methodologies can be found in the literature, the one that has been developed and peer reviewed and is being used for United States Air Force (USAF)/Department of Energy evaluation and is specific to aviation is contained in *Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels* (Allen et al. 2009). That approach was developed using government funds to ensure that Department of Defense purchases of alternative fuels conforms to the LCA requirements of Section 526 of the 2007 U.S. Energy Independence and Security Act (Sissine 2007).

The LCA process accounts for the six stages in the fuel-production life cycle: (1) acquisition of raw materials, (2) transport of these materials, (3) processing them into aviation fuel, (4) transport of fuel to the aircraft, (5) combustion of the fuel, and (6) end of life. (In the case of jet fuel, the end of life stage is not included in the analysis since the fuel is consumed in stage 5.) In the aggregate, the first four of these stages are often referred to as "well-to-tank" (where the tank is on the aircraft), and the combustion stage as "tank-to-wake." Analysis of GHG emissions is performed for each of these stages and includes all inputs and processes associated with a given

stage. Precise boundaries between each stage are defined so that each element is fully accounted for but without overlap between stages. Additionally, an overall system boundary is defined.

A recent report (Stratton, Wong, and Hileman 2010) analyzed several feedstocks for the FT or HEFA processing of aviation fuels using this methodology (see Table 18 and Figure 12). The nonpetroleum feedstocks coupled with FT processing were coal, natural gas, and switchgrass, as well as coal and switchgrass combined. The nonpetroleum feedstocks coupled with HEFA processing were soybeans, palm, rapeseed, *Jatropha*, algae, and *Salicornia*. Depending on assumptions (particularly those associated with land-use changes associated with growth of the feedstocks), these pathways were estimated to have life-cycle GHG emissions ranging from less than 1% of the conventional crude petroleum pathway to over 8 times greater than this pathway. Several pathways have estimated life-cycle GHG emissions that are less than half of the crude-to-conventional-jet-fuel pathway (switchgrass to FT fuel, *Jatropha* oil to HEFA, and *Salicornia* to HEFA and FT fuel). The variability that can be expected for given processes and feedstocks when land use and other uncertainties (e.g., yield per acre, energy required for growth, harvesting, and water extraction) are considered can be observed in the last column in Table 18.

There are other reports exploring the life-cycle GHG footprint of HEFA and FT processes for the production of alternative jet fuels. Figure 13 shows the results of an analysis of life-cycle GHG emissions for a variety of alternative fuels, including HEFA/HRJ, alternative (green) diesel, FT

Table 18. Life-cycle GHG emissions expressed as grams CO_2 equivalent (g CO_2e) per MJ of fuel energy content (adapted from Stratton, Wong, and Hileman 2010).

Pathway	Biomass Credit	Recovery	Feedstock Transport	Processing	Fuel Transport	Combustion	WTT N_2O	WTT CH_4	Land-Use Change	Total
Crude to conventional jet fuel	0	4.2	1.5	5.5	0.8	73.2	0.1	2.3	0	87.5
Crude to ULS jet fuel	0	4.2	1.5	7.3	0.8	72.9	0.1	2.4	0	89.1
Oil sands to jet fuel	0	19	1.3	5.5	0.5	73.2	0.1	3.1	0	102.7
Oil shale to jet fuel	0	41.2	0.6	3.3	0.6	73.2	0.2	2.5	0	121.5
Natural gas to FT fuel	0	4.6	0	20.2	1.2	70.4	0	4.6	0	101
Coal to FT fuel with (without) carbon capture	0	0.8	0.1	19.4 (117.2)	0.6	70.4	0	5.9 (5.7)	0	97.2 (194.8)
Switchgrass to FT fuel	-222.7	6.4	0.6	152.1	0.5	70.4	0.2	10.3	-19.8 to 0	-2.0 to 17.7
Coal and switchgrass to FT fuel, with carbon capture	-44.3	1.2	0.2	21.9	0.5	70.4	2	4.9	-3.9 to 0	53.0 to 56.9
Soy oil to HEFA/HRJ	-70.5	20.1	1.2	10.3	0.6	70.4	3.6	1.3	0 to 527.2	37.0 to 564.2
Palm oils to HEFA/HRJ	-70.5	4.9	3.1	10.3	0.6	70.4	5.1	6.3	0 to 667.9	30.1 to 698.0
Rapeseed oil to HEFA/HRJ	-70.5	17.2	3.1	10.3	0.6	70.4	22.4	1.3	0 to 43.0	54.9 to 97.9
Jatropha oil to HEFA/HRJ	-70.5	16.7	1.5	10.3	0.6	70.4	9.1	1.2	0	39.4
Algae oil to HEFA/HRJ	-70.5	29.6	0.3	10.3	0.6	70.4	8.1	1.8	0	50.7
Salicornia to HEFA/HRJ and FT fuel	-105.3	36.8	1.1	38.3	0.5	70.4	4.6	1.3	-41.9 to 0	5.8 to 47.7

Note: Some totals do not sum due to rounding.

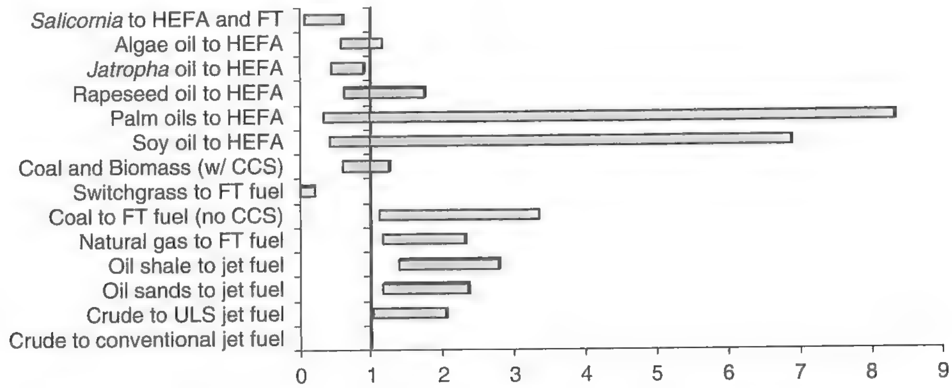

Figure 12. Relative life-cycle GHG emissions of several pathways for alternative jet fuels (conventional jet fuel = 1.0; adapted from Stratton, Wong, and Hileman 2010).

fuels, and conventional fuels (Kalnes, McCall, and Shonnard 2010; Shonnard, Williams, and Kalnes 2010).

Similar to the observations from Stratton, Wong, and Hileman (2010), feedstock selection plays a critical role in the contribution of the life-cycle GHG footprint to the process path. Tallow-based diesel and alternative jet fuel produced from hydroprocessing have the lowest life-cycle GHG signature since tallow is essentially a waste product and has minimal life-cycle GHG inputs. Alternative jet fuel made from *Jatropha* also has a lower life-cycle GHG footprint compared to conventional jet fuel.

Airports are encouraged to conduct or request from potential fuel producers detailed LCA analysis to determine the life-cycle carbon footprint of the fuels they intend to produce and the processes they intend to use. The previous estimates are meant to illustrate results from recent studies and are not intended to be a comprehensive or official representation of life-cycle carbon

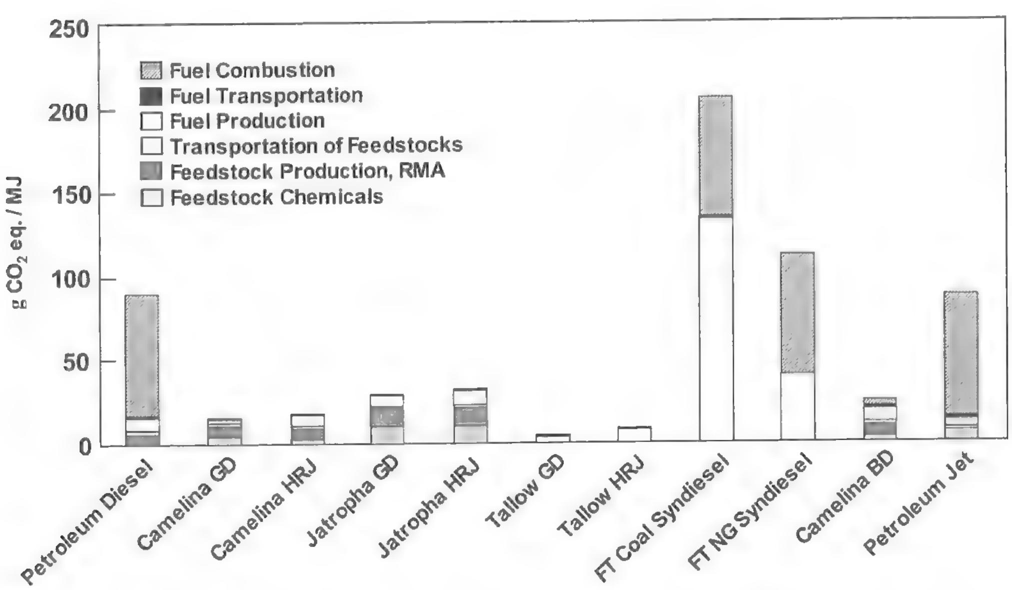

Figure 13. Life-cycle GHG emissions for conventional and alternative fuels, including green diesel (GD), HRJ, FT syndiesel, and biodiesel (BD). Adapted from Kalnes, McCall, and Shonnard 2010.

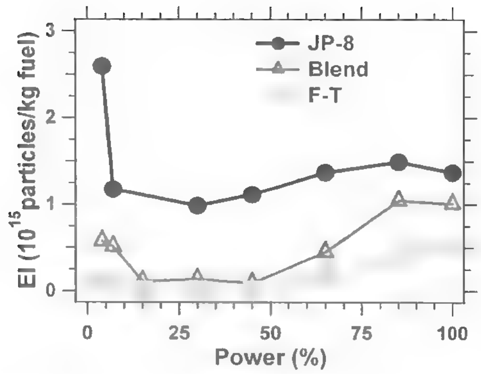

Figure 14. Particulate emission index (EI) for immediately behind a CFM-56 engine using conventional, Fischer-Tropsch, and blended fuels as measured by AAFEX. Source: Beyersdorf and Anderson 2009.

estimates. Given the many uncertainties with respect to feedstocks, production and delivery, and land-use change impacts, this remains an intensely debated and active field of research.

E.2 Reductions in Criteria Pollutants, Particularly $PM_{2.5}$

Another potential benefit of using alternative fuels is the reduction in emissions that affect local air quality, in particular SO_x and PM. These emissions can lead to respiratory diseases, such as asthma, and are major contributors to acid rain, smog, and reduced visibility (FAA 1997a; EPA 1999). In this section, an overview of the potential of alternative fuels to reduce or mitigate emissions of these pollutants is presented.

Oxides of sulfur present in jet fuel are precursors and indicators of particle and $PM_{2.5}$ formation. $PM_{2.5}$ is known to cause serious health problems and is regulated with separate standards by the EPA (EPA 2011). Furthermore, as a criteria pollutant, high levels of $PM_{2.5}$ can lead to areas in which airports are located to be designated as non-attainment zones, with potential negative consequences to airport growth and operations.

As alternative fuels are being qualified as blends with petroleum-based jet fuel, the alternative components of these fuels are essentially sulfur-free. Benefits of alternative fuel regarding $PM_{2.5}$ emissions have been measured by the USAF and by commercial tests. Figure 14 shows the particle emission index for conventional fuel, Fischer-Tropsch fuel, and a blend of the two at different thrust levels. The decrease associated with the blend becomes larger as the proportion of the Fischer-Tropsch fuel increases (Corporan et al. 2007). These benefits are substantial when compared to current petroleum-based fuels having typical sulfur contents of approximately 700 parts per million (Taylor 2009).

In addition to sulfur content, PM formation is also linked to the presence of aromatic compounds in the fuel. Since levels of aromatics in HEFA fuels and fuels produced with Fischer-Tropsch processes are typically low (Hileman et al. 2009), there would also be a reduction in the generation of PM from these fuels due to this effect (Morser et al. 2011).

APPENDIX F

Economic Benefits

Regional economic impacts are a function of the inputs used to produce a final good or service, in this case alternative jet fuel. Processing a commodity and producing a good contributes to the local or regional economy to the extent that local inputs are used. Payments for wages and salaries for plant employees; locally purchased supplies, materials, and utilities; and payments to local financial institutions represent new activity in the local economy as a result of production activities. These initial local expenditures are referred to as direct impacts. Direct impacts in turn set in motion subsequent rounds of spending and re-spending that result in secondary impacts called indirect and induced effects. The subsequent spending and re-spending as a result of additional economic activity is often referred to as the multiplier effect. These effects are most often estimated using input–output models. IMPLAN and RIMS models are widely accepted and used for estimating regional economic impacts (Leistritz 2003).

A number of factors affect the potential regional economic impact of an alternative fuel production facility: (a) choice of feedstock, (b) extent of study area, (c) nature of ownership, (d) specific model/analysis assumptions, and (e) differences in study areas.

F.1 Choice of Feedstock

The choice of feedstock will affect the degree of regional economic impact. The general assumption for agricultural inputs is that the product is already being produced and sold in an alternative market. For example, corn used in ethanol production would likely be used for animal feed or exported in the absence of ethanol production. Thus payments to producers for the commodity with existing markets would occur regardless of the presence of a processing plant. The direct impacts of the processing operation would include payments for locally produced inputs such as labor and utilities but would not include commodity feedstock purchases such as vegetable oil that already have established markets. However, if the feedstock has little or no alternative market, as is the case with agricultural residues, the sale of these feedstocks to an alternative fuels processing facility would represent a new revenue source for farmers. Accordingly, payments for feedstocks without established markets would be included in the estimate of regional economic impacts. Considering feedstock costs will likely represent a substantial operating expense for any processing facility; inclusion of feedstock cost would likely increase regional economic impacts substantially. Leistritz et al. (2009) compared the regional economic impacts of a biomass-based (cellulosic) ethanol plant with a corn-based facility. The cellulosic biorefinery had a much greater regional economic impact because payments to producers for feedstock represented new income to farmers and others in the supply chain while the corn used at a corn-based facility had other markets.

F.2 Extent of Study Area

The definition of the study area can also affect impact analysis results. Studies have estimated impacts for a single county (Peters 2007; Low and Isserman 2008), a small multi-county site area (Swenson and Eathington 2006), and the economy of an entire state (Hodur, Leistritz, and Hertsgaard 2006; Flanders et al. 2007). There is no right or wrong approach to defining the study area. The definition of the study area often depends on who constitutes the primary audience for the study (e.g., local leaders or state decision makers). Generally speaking, the larger the study area, the larger the regional economic impact. For example, impacts measured at the state level will always be greater than those for a single county or a multi-county area within the state.

F.3 Nature of Ownership

The degree of local ownership can have a substantial impact on a regional economy. If a processing facility is largely or wholly owned by farmers or other local investors, facility profits will be distributed to these local owners, and a substantial portion may be spent locally. If the facility is owned by a corporation headquartered elsewhere, the profits and potentially some operating expenses such as centralized accounting, marketing, and other administrative expenses may leave the local area. Local operating expenditures are likely to be greater for a locally owned facility, while many operational activities might be centralized off-site for a corporately owned facility. The extent of local ownership can have a substantial influence on impact estimates. Swenson and Eathington (2006) present estimates for a 50-million-gallon-per-year (MGY) ethanol plant employing 35 workers. With no local ownership, the project supported a total of 207 jobs (direct and secondary employment). When local ownership was increased to 25%, the direct and secondary employment increased by 15% to 239 jobs. At 50% local ownership, direct and secondary employment increased 29% to 265 jobs, and at 75% local ownership it increased by 42% to 293 jobs. (It should be noted that this study was done at a time when profits in the ethanol industry were very high. Results would likely be different if current profit levels were used.)

F.4 Model/Analysis Assumptions

Differences in assumptions incorporated in the impact model and analysis procedure may also affect regional economic impacts. For example, Hodur, Leistritz, and Hertsgaard (2006) estimated the economic impacts of a North Dakota corn ethanol plant. Because very little of the corn that would supply the plant came from the local area, no local corn price premium was included in the analysis. Project attributes can also substantially affect impact estimates. The employment multiplier in Hodur, Leistritz, and Hertsgaard (2006) might appear inflated at first glance. However, the plant was fueled by North Dakota lignite coal, and the coal purchased to fire the plant represented a net increase in coal production for the state. In fact, coal purchases represented 49% of the plant's direct impacts. In this context, the resulting employment estimates appear reasonable.

F.5 Differences in Study Areas

Demographic and infrastructure characteristics of the local area that is home to an alternative fuels production facility will also affect regional economic impacts. A processing facility located in or near a substantial trade center with a somewhat diversified, self-sufficient economy will have larger secondary impacts, other things equal, than a sparsely populated rural site. Low and Isserman (2008) analyzed the impact of 100-MGY ethanol plants at two locations in Illinois. One site county was described as mixed rural with a population of 109,000, while the other site county was rural with a population of less than 9,000. Employment impacts (direct and secondary employment) in the more urbanized county were nearly twice that of the rural county with the smaller population.

APPENDIX G

Possible Economic Implications of Regulation

Demand for alternative jet fuel will be affected by the passage of state or federal legislation that mandates use of bio-derived fuels or taxes emissions from the use of jet fuel. To date, the U.S. Congress has not passed legislation that creates a market for carbon in the United States, but has done so for other pollutants (see Section G.2). Moreover, the global popularity of using credits for limiting pollutants and emissions makes it possible that additional variations on emissions trading will be mandated in the United States. Currently the EPA has purview over these issues and is a source of useful information, including summaries of national markets in different pollutants on its web site (EPA 2010b). Examples of existing cap-and-trade programs (which cap a maximum amount of emissions and allow those emitting them to trade emission credits) in the United States are the nationwide Acid Rain Program (EPA 2010a), the regional NO_x Budget Trading Program (EPA 2010d) in the Northeast, and the Regional Greenhouse Gas Initiative, which limits GHG emissions from electricity generation in ten participating Northeast states (RGGI 2011).

G.1 National Ambient Air Quality Standards

Airport activity is subject to compliance with all federal regulations, including EPA regulations under the CAA (FAA 1997a). The EPA establishes NAAQS for a series of criteria pollutants, including NO_x, SO_2, and PM, which can be present in or result from the exhaust of jet engine emissions. (Such emissions together account for a very small percentage of jet engine emissions.) Geographic areas in which concentrations of these pollutants are determined to be in excess of the NAAQS are designated as NAAs and are subject to formulating a SIP to bring the area back into compliance (FAA 1997a).

SIPs can affect airports in two important ways. First, an airport in an NAA may be subject to regulation targeted at bringing the area back into compliance with NAAQS. Federal aviation statutes preclude state regulators from imposing emissions requirements on aircraft, but they can affect other non-aircraft sources at the airport, such as on-road vehicles (including cars, taxis, and shuttles), construction equipment, power plants, and other stationary sources. Second, if an airport is in an NAA and has plans for a development project, the airport has to show that the project will be in "conformity" and will not cause or contribute a further violation of a SIP before it can receive federal funding. It is important to note that one of the most problematic sources of emissions that may lead to a violation of a SIP is emissions from construction equipment.

Alternative jet fuels may help airports in NAAs meet the goals specified in SIPs because of their potential to have lower emissions levels of criteria pollutants such as SO_x, NO_x, and PM as compared to conventional jet fuel. This may allow airports to save time and cost in the approval process for development projects. It may also allow airports to grow their operations without violating existing SIPs.

G.2 Emission Reduction Credits

The Clean Air Act of 1990 created an opportunity for industry to buy and sell ERCs tied to atmospheric pollutants including sulfur dioxide (SO_2), NO_x, carbon monoxide (CO), PM, lead, and volatile organic compounds (VOCs) (EPA 1990). An airport operating within a non-attainment area could theoretically generate and sell ERCs if it can demonstrate that it is removing criteria pollutants through the supply of cleaner aviation fuel. Alternative aviation fuels can potentially contain less SO_2 and PM than conventional petroleum-based jet fuel (see Section E.2). However, while creating a market for ERCs, the Clean Air Act also created restrictions based on New Source Performance Standards such that any entity operating a site subject to NSPS regulations *must* reduce emissions of criteria pollutants and cannot claim ERCs.

G.3 Regional Greenhouse Gas Initiative

The Regional Greenhouse Gas Initiative (RGGI) is a program in which ten states—Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont—have capped CO_2 emissions from electric power generation and will reduce such GHG emissions by 10% by 2018 (RGGI 2011). Although it is limited to power generation so has no impact on aviation GHG, RGGI is the first mandatory, market-based GHG emissions reduction program in the United States and could be used as a model for expansion into other industries. In the RGGI model, each state has individual CO_2 budget trading programs that limit emissions of CO_2 from electric power plants operating within the state, issue CO_2 allowances, and establish participation in regional CO_2 allowance auctions. Regulated power plants can use CO_2 allowances issued by any of the states, so the ten programs act as a single regional compliance market for CO_2 emissions.

G.4 EPA Renewable Fuel Standards

The Environmental Protection Agency adopted an RFS called RFS-2 in February 2010 (EPA 2010c). While aviation does not have a required biofuels contribution under RFS-2, producers of alternative fuel for aviation may generate benefits in the form of tradable credits for fuels merited by their ability to provide benefits as quantified by the Renewable Index Number of those fuels.

G.5 Federal Rules for Purchase of Alternative Fuels

Section 526 of the 2007 Department of Energy Authorization mandates that U.S. government buyers can only purchase alternative fuels if their life-cycle GHG footprint is less than that of petroleum-based fuels (U.S. Congress 2007). In the case of alternative jet fuels, this can be of relevance to airports that have or want to attract government customers such as the Air National Guard.

Furthermore, the U.S. Air Force and DOE have published peer-reviewed procedures to help alternative jet fuel companies verify that their products meet the requirements of Section 526 (NETL 2008; Allen et al. 2009). These documents can also be of value to airports interested in a better understanding of the process of determining the life-cycle GHG footprint of alternative jet fuels and of overall compliance with Section 526.

G.6 Carbon Markets

The U.S. Congress has had difficulty in finding a political consensus on how to deal with greenhouse gas emissions, even as some states and municipalities pass rules and/or legislation that address this issue within their jurisdictions. The most notable example is California's Global Warming Solutions Act of 2006, also known as Assembly Bill 32, which requires the state to

develop regulations to reduce GHG (CAEPA 2009). It is important to note that AB32 does not apply to jet fuel. As of the first quarter 2011, it seems unlikely that Congress will introduce a carbon market system within the United States in the near future.

Nevertheless, there are developments in other parts of the world that may have an impact on U.S. airports and airlines. For example, the ICAO is currently analyzing a CO_2 standard for new aircraft.

The largest active market for carbon trading is in the European Union. The EU emissions trading scheme is a cap-and-trade system—it caps the overall level of emissions and allows participants to buy and sell allowances as they require (EC 2010). The ETS has been in effect since 2005 for specified energy-intensive activities (power stations and other combustion plants, oil refineries, coke ovens, iron and steel plants, and factories making cement, glass, lime, bricks, ceramics, pulp, paper, and board), and as a result of growing European public concern over global warming, the EU is leading the effort to control greenhouse gas emissions from aviation sources. EU legislation requires that all airlines landing at EU airports participate in the European Greenhouse Gas Emission Trading Scheme as of January 1, 2012, and monitor and report their CO_2 emissions and ton-kilometer data from January 1, 2010 (EC 2003). These initiatives are being opposed by non-European airlines on the grounds that the EU has no jurisdiction over international flights because regulation of international flights is the exclusive right of ICAO, but the EU contends that since the European Greenhouse Gas Emission Trading Scheme treats all airlines entering the EU in the same manner, it is permitted under ICAO regulations. If it is determined that all airlines that fly into European airports are subject to the ETS, it is expected that airlines that use bio-derived fuel may use fewer allowances than with conventional petroleum-based jet fuel (EC 2003) and, therefore, may be able to reap an economic benefit.

Even though there is still uncertainty with respect to aircraft GHG emission regulations, the airline industry has been proactive in adopting a common position of a commitment to carbon neutral growth starting in 2020 (IATA 2009). The industry realizes that alternative jet fuels with a life-cycle GHG footprint smaller than conventional jet fuel can help airlines meet their carbon-neutral growth goals. Furthermore, in the event that GHG emissions targets under the EU's ETS or other potential cap-and-trade mechanisms become mandatory, alternative jet fuels may also help airlines meet their cap and reduce the need to purchase emissions credits. Airports that offer alternative jet fuels could provide benefit to airlines.

It is important to indicate that carbon regulation, including cap-and-trade systems, will need to be crafted carefully to be effective at improving the environmental performance of air transportation. There is a concern among airlines that mechanisms that result in excessive monetary payments may affect the carriers' ability to invest in new technology such as aircraft and engines with reduced fuel consumption. Furthermore, airlines are concerned that funds collected through environmental charges may not be re-invested in air transportation, and thus needed investments in air traffic control modernization, alternative jet fuels, and airport infrastructure may not occur.

APPENDIX H

Financial Considerations

The goal of this appendix is to provide guidance to project developers and other decision makers with respect to the key financial considerations that must be addressed when considering an alternative fuels project. This is intended to serve as a road map to the issues that are most likely to surface when putting together the financial and business plan for this kind of facility.

When creating the business case for alternative fuel processing facilities, the project developer needs to pay special attention to risk factors (i.e., those variables outside her/his control) that may have a substantial impact on the project's economic viability. In particular, as of 2011, project developers need to recognize that alternative fuel facilities are likely to require large amounts of capital, employ technology that is unproven at scale, and operate in an uncertain market environment. As such, the projects would likely be considered high risk by financiers. Project developers need to take into account that different financial supporters have different attitudes toward risk and require different kinds of assurances before committing to support a venture.

H.1 Sources of Finance

Project developers of alternative jet fuel production facilities can seek funding from both private- and public-sector organizations and may use a mixture of both to create a viable finance structure.

H.1.1 Private Sector

Private-sector funders are made up of a diverse range of private and publicly traded entities that offer different products, including equity, senior debt (similar to commercial bank loans), and mezzanine debt (debt with equity characteristics). Typically, projects require both equity and senior debt, and often mezzanine debt. The mix of these products is referred to as the project's "capital structure."

Each of these products has a different risk/return profile: equity providers take on the highest level of risk within the capital structure and therefore require the highest rates of return to justify their investments; providers of bank debt accept lower rates of return because they receive interest and get paid before equity holders if the investment goes bankrupt; mezzanine debt providers expect rates of return that are between equity and debt holders.

H.1.2 Public Sector

Public sources of financing include local, regional, and the federal governments. Project developers should explore diverse local and regional initiatives that may be in place to support

regional economic development. The alternative fuel industry is currently a high priority for the federal government because of its potential to generate jobs, reduce dependence on foreign oil, and improve the quality of the environment. The federal government, primarily through the USDA and DOE, is providing incentives such as grants, loans, loan guarantees, subsidies, and tax credits.

The USDA offers extensive support programs to encourage rural development (USDA 2010e) and is committed to supporting the development of alternative aviation fuel as part of these initiatives. USDA recently joined with CAAFI, the ATA, and the Boeing Company in a resolution to "accelerate the availability of sustainable aviation biofuels in the United States, increase domestic energy security, establish regional supply chains, and support rural development" (ATA 2010a). The agreement includes the formation of a Farm to Fly working group that will identify and facilitate funding of feedstocks and production facilities focused on alternative aviation fuels.

H.1.3 Biorefinery Assistance Loan Guarantee Program—Section 9003 of 2008 Farm Bill

The USDA program of particular relevance to a developer of a jet fuel biorefinery is the Biorefinery Assistance Loan Guarantee Program (USDA 2010n). This program, administered by USDA Rural Development, provides loan guarantees for the construction or retrofitting of rural biorefineries to assist in the development of new technologies for the development of advanced biofuel made from renewable biomass other than corn (USDA 2010d). Such loan guarantees can be used to support private-sector loans and are intended to make it easier to obtain financing by reducing the risks a banker would have to assume. As a result, this agency should be contacted by any airport that is interested in biorefineries.

H.2 Business Case Evaluation Criteria

In addition to being aware of the different possible sources of finance, it is helpful for project developers to understand business case evaluation criteria that are likely to be used by potential financial supporters. The evaluation of any business case proposal is a high-level assessment of the reasonableness of the project, including the assumptions regarding a project's inputs and outputs, their impact on expenses and revenues, and how they affect the economic viability of the enterprise. A key aspect of the business case evaluation is to help identify the elements of the project that may have the greatest impact on its viability.

Important evaluation criteria for alternative fuel business plans are discussed in the following six subsections.

H.2.1 Customers and Other Stakeholders

- Who are the customers; what is their interest in the project?
- Are the customers willing to enter into binding purchase agreements to help reduce the financial risk and solidify the project's financial viability? Would customers agree to long-term purchase agreements? Do the fuel buyers need to assume all the risk in a cost-plus contract or a fixed price agreement, or will the various participants in the project share in the risks?
- Which stakeholders have the greatest interest in the project and does that interest translate into them being willing to take a greater share of the risk? These stakeholders may include users of the alternative jet fuel as well as users of alternative diesel, renewable electric power, and other by-products.

H.2.2 Demand for Alternative Jet Fuel

- Is there sufficient demand for the product(s) in the region to justify an alternative jet fuel facility? What would be the minimum economic size for the processing facility?

H.2.3 Feedstocks and Production Technology

- What are the feedstock's availability, supply reliability, and cost?
- What is the project's overall environmental sustainability, including its impact on water use, land use, and life-cycle GHG benefits? It is likely that projects that are identified as not sensitive to these considerations may face stiff opposition and may engender less community support, both of which could increase the project's risk profile.
- Will new technologies for production of alternative fuels affect the project? For instance, novel production methods could divert feedstocks to more efficient processes or reduce the cost of competing fuels.

H.2.4 Capital Costs

- Can the required financial capital be attracted? This is particularly important for all projects involving new technologies. Is the engineering and design firm willing and able to guarantee both construction costs and development schedules? Are the technology providers willing and able to guarantee performance of their technology offering?

H.2.5 Permitting and Regulatory Concerns

- Have all regulatory, permitting, and social equity issues been identified and satisfactorily addressed? If not, the project may be delayed, resulting in higher capital costs.
- If existing or new federal, state, and local governmental policy is important to the project's economic viability, can the policy be changed during the project's life and how would that affect the project's viability? This applies to policies and regulations on which any GHG or other environmental credits and financial mechanisms rely and to feedstock or fuel price subsidies, if any.
- Successful projects depend on all the involved parties honoring their contractual obligations. Which of those obligations are essential to the project's success and what are the implications if one or more contracts are broken? This would include feedstock supply, infrastructure availability, and customer purchases.

H.2.6 Management Team

- What is the quality and depth of the team that will manage this project?

For new ventures in mature businesses, the business case evaluation can be based on benchmarks from existing businesses. The alternative fuels industry, in particular for aviation use, is a new and developing field, involving new technologies, feedstocks, and logistics that make it difficult to identify reliable benchmarks for comparison. A good starting point for evaluating business cases for aviation alternative fuels is the information from demonstration projects [see Appendix J and IATA (2009)], although project developers need to be aware that this information may change as the industry matures. Over time, as commercial-scale projects are developed, more information will be available to help in the evaluation of this kind of venture.

APPENDIX I

Regulatory Considerations

There are three general regulatory elements that should be considered in the evaluation of an alternative jet fuel project. For each one of these elements, this section details the main and associated information that the airport should consider when evaluating alternative jet fuel projects.

The main regulatory elements are:

1. FAA policies and regulations,
2. Environmental reviews and permitting, and
3. Energy policy.

The following subsections outline and present the important points associated with these three regulatory elements.

I.1 FAA Policy and Regulatory Framework

The FAA compiles and maintains a number of documents, including FAA Advisory Circulars, FAA Orders, and references to other documents that must be considered when assessing the viability of alternative fuel infrastructure. The following subsections identify these documents and provide key excerpt material, when appropriate, to provide the reader with an overview of the policy and regulatory framework pertaining to conventional and alternative jet fuels in the airport setting.

I.1.1 FAA Advisory Circulars, Orders, Regulations, and Peripheral Documentation

FAA policies and regulations largely control what can and cannot be done in the airport setting. The construction and operation of alternative jet fuel infrastructure is no exception. The FAA compiles and maintains a number of documents, including ACs, Orders, and references to other documents that should be considered when evaluating the feasibility of placing alternative jet fuel infrastructure in the airport setting. In addition, given the complex technical issues surrounding fueling system and airfield design, engaging an aviation consultant engineer familiar with these topics may be advisable to assist with locating a processing facility.

The FAA and FAA-related documents most likely to be relevant for alternative jet fuel projects are as follows (see Section 6 for more information):

- FAA AC 150/5070-6B, Airport Master Plans
- FAA AC 150/5200-33, Hazardous Wildlife Attractants on or Near Airports
- FAA AC 150/5230-4A, Aircraft Fuel Storage, Handling, and Dispensing on Airports

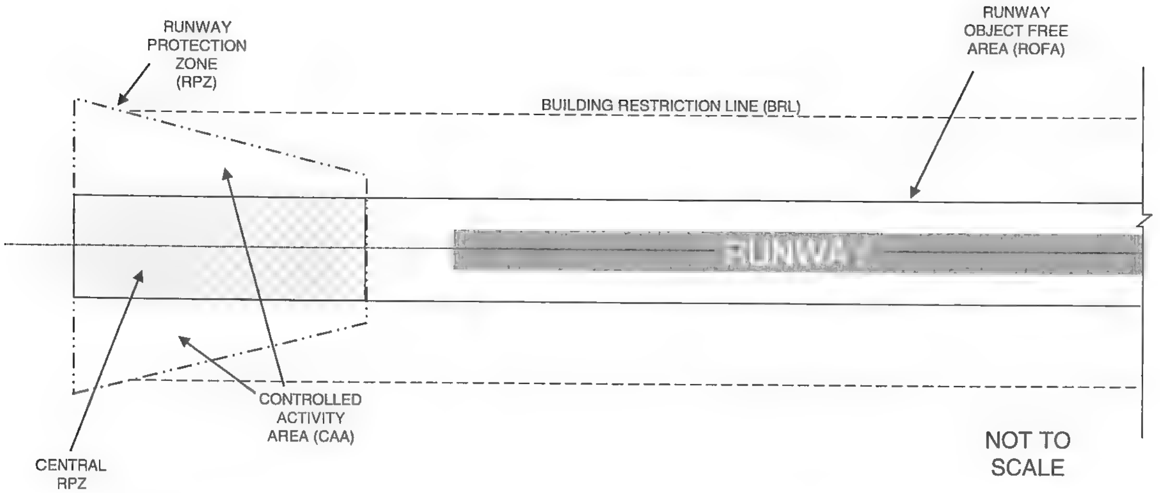

Figure 15. ***Controlled activity area. Source: Fig. 2-3, FAA AC 150/5300-13 (FAA 1989).***

- FAA AC 150/5300-13, Airport Design
- FAA Order 5050.4B, National Environmental Policy Act (NEPA) Implementing Instructions for Airport Projects
- FAA Order 5190-6b, Appendix R, Airport Compliance Manual
- FAA Order 5190-7, Minimum Standards for Commercial Aeronautical Activities
- FAA Order 1050.1E, CHG 1, Environmental Impacts: Policies and Procedures, Paragraph 304
- Title 14 of the Code of Federal Regulations (CFR) Part 77, Objections Affecting Navigable Airspace
- Title 14 of the Code of Federal Regulations (CFR) Part 139, Certification of Airports
- National Fire Protection Association (NFPA) 407, Standard for Aircraft Fuel Servicing
- Best Practices for Environmental Impact Statement (EIS) Management
- *Environmental Desk Reference for Airport Actions*

As with any airport facility, fuel production and storage facilities must comply with FAA AC 5300-13, Airport Design (FAA 1989), which contains definitions for RPZs and ROFAs (see Figure 15 and Figure 16). This AC prohibits objects nonessential to air navigation or ground

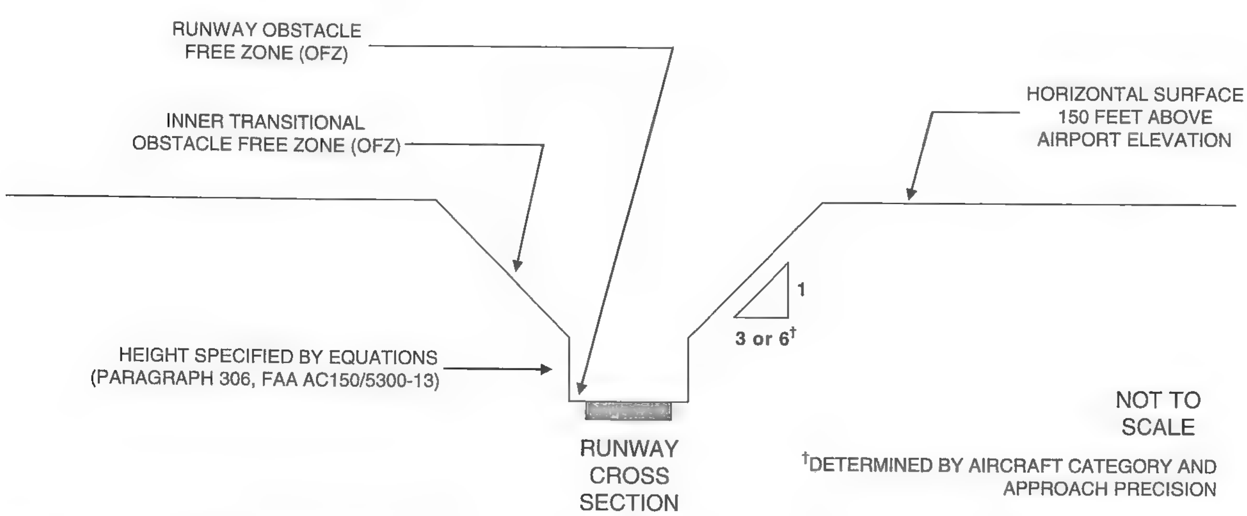

Figure 16. ***Obstacle free zones around runways. Source: Fig. 3-5, FAA AC 150/5300-13 (FAA 1989).***

maneuvering purposes in ROFAs and states that fuel storage facilities may not be located in the RPZ. FAA Order 5190.6B, Airport Compliance Manual (FAA 2009), reiterates that fuel storage facilities are a prohibited RPZ land use but mentions an exception for underground fuel storage tanks in controlled activity areas, which are the portions of the RPZ outside the central RPZ. Additionally, 14 CFR Part 77, Objections Affecting Navigable Airspace (FAA 1993), establishes standards for determining obstructions to air navigation by defining criteria for imaginary surfaces that must not be pierced by any structure, including fuel production and storage facilities. Another consideration is that the proposed project must be shown on the airport layout plan, as indicated in FAA Order 5190-6B (FAA 2009). An unconditional ALP approval is required for the construction of an alternative jet fuel production facility on an airport.

FAA AC 150/5230-4A, Aircraft Fuel Storage, Handling, and Dispensing on Airports (FAA 2004), states that NFPA's 407 Standard for Aircraft Fuel Servicing (NFPA 2007) lists specifications for the design, operation, maintenance, and location of fuel storage areas and aircraft fueling devices. Generally, it requires that fuel pumps and storage tanks and facilities be at or below ground level. However, NFPA 407 itself does not give many specifics on the design and siting requirements of fuel facilities. NFPA 407 allows the authority having jurisdiction to establish these requirements. The authority having jurisdiction may be a federal, state, local, or regional department or individual.

The constructions of alternative jet fuel facilities on or proximate to an airport will require an environmental review to adequately assess and disclose the potential for impacts to the environment from such a facility. FAA Order 5050.4B, National Environmental Policy Act (NEPA) Implementing Instructions for Airport Projects (FAA 2006b), provides information relative to the environmental review process that may be required. Order 5050.4B specifies three types of reviews: categorical exclusions, environmental assessments, and environmental impact statements. The type of review required will be determined by the responsible FAA official with jurisdiction over the project.

The type of review will also depend on the estimated significance of the impact of the project on the environment. In some cases, the extent of government agencies' review expands depending on the circumstances that are likely to be highly controversial on environmental grounds. Both FAA Order 1050.1E and FAA Order 5050.4B stress the importance of early contact with the FAA to avoid delays in the NEPA process.

Alternative jet fuel processing plants located outside of the airport limits are not subject to the FAA policies and regulations governing on-airport facilities; however, near-airport and off-airport facilities must still comply with 14 CFR Part 77. For example, objects such as light poles, trees, construction cranes, and even tall buildings (sometimes miles away from the airport) can be in violation of 14 CFR Part 77 and would, therefore, present a potential hazard to aircraft operating in the area. Form 7460-1, Notice of Proposed Construction or Alteration, needs to be completed and filed with the FAA prior to construction for an airspace analysis and determination for on- or off-airport projects.

In addition to the FAA documents discussed previously, it is important to indicate other resources available to jet fuel handlers. For example, the American Transport Association publishes ATA Specification 103: Standard for Jet Fuel Quality Control at Airports (ATA 2009c). This document includes recommended specifications that have been developed to provide guidance for safe storage and handling of jet fuel at commercial airports. While these recommendations are not mandatory, they are very closely followed by all major airlines and airports in the United States.

I.1.2 Airport Improvement Program Applicability

Any costs associated with alternative jet fuel production are not AIP eligible. Refining and manufacturing of aviation fuels, whether from conventional or alternative feedstocks, are not aeronautical activities. The handling, storing, and delivery of jet fuel into an airplane may be con-

sidered an aeronautical activity as long as 100% of the fuel is delivered to aircraft on the airport and not distributed elsewhere. Therefore, on-airport fuel storage is eligible but only using non-primary airport entitlements. Furthermore, since the production of alternative fuels is not an aeronautical activity, any leases will need to be at fair market value. Ancillary project elements, such as site preparation and utilities, may be eligible for AIP funding.

The following sections present more information on possible AIP applicability for certain fuel-related projects at airports. They are meant to illustrate some details of how AIP funding works and how it can relate to alternative jet fuel. For more information, airports are encouraged to contact their local FAA office. Contact information for the FAA regional offices is available at http://www.faa.gov/about/office_org/headquarters_offices/arp/regional_offices/.

Fuel Facilities and AIP

The AIP provides grants to public agencies and, in certain circumstances, to private owners and entities to plan and develop public-use airports (FAA 2010b). An airport improvement project must meet numerous requirements before becoming eligible for funding. In general, projects related to enhancing airport safety, capacity, security, and environmental concerns are eligible for AIP funding. On the other hand, projects related to airport operations and revenue-generating activities are usually not eligible for AIP funding.

Projects related to fuel infrastructure are typically ineligible for AIP funding, but there are certain circumstances under which they become eligible. For example, Paragraph 515(a) of the *Airport Improvement Program Handbook* states that new fuel farms at non-primary airports may be eligible for AIP funding provided that financing for other airfield projects with higher priority has been secured (FAA 2005b). Furthermore, the FAA Vision 100—Century of Aviation Reauthorization Act included a provision to allow for revenue-producing facilities such as hangars and fuel farms to obtain AIP funding if certain conditions are met (U.S. Congress 2003). The intent of the policy is to "support the construction of new facilities which add additional revenue producing capability for the facility." Before any AIP funding is allowed under this provision, a number of conditions must be met, including (a) a determination by the FAA that the airport's airside needs have adequate funding, (b) verification that current FAA Safety Area and Runway Protection Zone standards are being met, and (c) that the federal share of these facilities is funded with non-primary entitlements (FAA 2010b).

These provisions refer specifically to fuel storage; however, AIP funding for alternative jet fuel production is not eligible. Refining and manufacturing of aviation fuels, whether from conventional or alternative feedstocks, are not aeronautical activities.

Definition of Aeronautical Activities and Its Relationship to Alternative Fuels Production

The definition of an aeronautical activity as defined in AC 150/5190-7 includes "any activity that involves, makes possible, or is required for the operation of aircraft or that contributes to or is required for the safety of such operations" (FAA 2006a). Furthermore, AC 150/5190-7 states that aeronautical activities include "any other activities that, because of their direct relationship to the operation of aircraft, can appropriately be regarded as aeronautical activities." Common aeronautical activities include but are not limited to general and corporate aviation, air taxi and charter operations, scheduled and nonscheduled air carrier operations, and sale of aviation petroleum products.

The handling, storing, and delivery of jet fuels into an airplane may be considered an aeronautical activity as long as 100% of the fuel is delivered to aircraft on the airport and not distributed elsewhere. Therefore, on-airport fuel storage (but not production) may be eligible but only using non-primary airport entitlements.

Other Considerations Regarding AIP and Alternative Jet Fuel Facilities

In addition to the items discussed previously, there are other considerations related to AIP and associated mechanisms that should be considered, including:

Section 25, Airport Revenues of the FAA's Airport Sponsor Assurances, specifies requirements for those airports having to meet grant assurances (FAA 2005c). One of the provisions states that "all revenues generated by the airport and any local taxes on aviation fuel . . . will be expended by it for the capital or operating costs of the airport; the local airport system; or other local facilities which are owned or operated by the owner or operator of the airport and which are directly and substantially related to the actual air transportation of passengers or property; or for noise mitigation purposes on or off the airport." Consequently, revenues from the sale of alternative jet fuel would have to be re-invested in the airport or airport system in order to meet grant assurances.

The Airport Grant Assurance Compliance Certification Form provides further support to this interpretation. Section K, Utilization of Airport Revenue, states that airports subject to any federal agreement are obliged to "apply revenue derived from the use of airport property toward the operation, maintenance, and development of the airport. Diversion of airport revenue to a non-airport purpose must be approved by the FAA" (FAA 2005a).

Other questions regarding compliance with grant obligations and other funding mechanisms for those areas of alternative jet fuel production and distribution for which implications to grant assurances are new in nature or otherwise unclear are best handled by coordinating with the appropriate local Airport District Office. In addition, adherence to items in the Airport Sponsor Assurances (FAA 2005c) and Airport Grant Assurance Compliance Certification Form (FAA 2005a) will provide the best avenue for compliance.

I.2 Environmental Reviews and Permitting

Environmental reviews and permitting will be requisite activities in the planning process for any alternative jet fuel production and distribution project. Jurisdictions at the federal, state, and local levels require permits for those activities or facilities that they view as affecting the environment, safety, or equity of the surrounding population. Alternative jet fuel plants affect each of these three components. In general terms, the main categories of interest in the environmental review and permitting process tend to be the following:

- Water quality, including environmental impact on drinking water, groundwater, wastewater, and surface waters including storm water, coastal areas, wetlands, or floodplains.
- Air quality, including environmental impact of gaseous and other emissions.
- Impacts to endangered species and historic, coastal, or other environmental resources by facility construction, operation, maintenance, or access.
- Land quality, including solid waste disposal, hazardous waste handling and disposal, and spill prevention, reporting, and cleanup.
- Land-use planning and zoning, including impacts to shared infrastructure such as roads and railways.

I.2.1 Environmental Review

At the federal level, alternative jet fuel projects need to comply with NEPA and applicable laws protecting sensitive environmental resources. NEPA outlines a process by which agencies are required to determine if their proposed actions have significant environmental effects. Depending on a number of factors, including the severity of the environmental effects, a CE, EA, or EIS may

be required (see FAA Order 1050.1E for more information). Environmental effects that may need to be analyzed include growth-inducing effects related to changes in land use, population density, and related effects on air and water and other natural systems, including potential impacts to ecosystems that an action may cause. In particular, the environmental issues addressed in the *Environmental Desk Reference for Airport Actions* (FAA 2007) or Appendix A of Order 1050.1E should be investigated during the NEPA process. This must occur thoroughly before FAA makes a decision on approving an alternative jet fuel facility.

For alternative jet fuel projects on-airport, airports should refer to FAA Order 1050.1E, which is the FAA's umbrella guidance for NEPA compliance. Installation of on-airport fuel facilities requires the FAA to issue an unconditional approval to an airport layout plan. This requires the FAA to complete its environmental analyses under NEPA and other special purpose laws (FAA 2007).

At the state and local level, there is a high degree of variation in terms of environmental review and permitting requirements and regulations. Many states are developing review processes and integrated guidance materials on environmental review and permitting activities relative to infrastructure that may be applicable to alternative jet fuel projects (see Section 6.2). Furthermore, the EPA maintains a database of state-specific regulatory information at http://www.epa.gov/lawsregs/states/index.html#state. Readers should consult this resource for guidance specific to their local conditions.

I.2.2 Environmental Permitting

This subsection provides an overview of federal, state, and local permitting processes to identify the breadth of permitting requirements that might be expected in developing alternative fuel production, storage, and distribution infrastructure. This is not intended to be a comprehensive review since requirements and processes vary from jurisdiction to jurisdiction.

There are various motivations for permitting. Environmental permitting encompasses numerous and detailed processes instituted to ensure protection of public health, safety, and environmental quality. These permitting requirements vary from state to state and also have local nuances with respect to county, city, and other jurisdictional requirements—and they apply to the production of alternative fuels as they do to any other facility. In addition, federal requirements under NEPA and other federal regulations may be applicable to alternative jet fuel facilities depending on location and proximity to state or federal waters, endangered species, and historic and archeological resources.

Most of the existing guidance issued by jurisdictions pertains to biodiesel facilities, not specifically to alternative jet fuel. However, the permitting process for biodiesel should be a reasonable approximation for that of alternative jet fuel. For example, the State of Washington has two publications pertaining to biodiesel permitting. One of them is a fact sheet that lists the permits, regulations, and tax benefits associated with a biodiesel plant (State of Washington 2010a). Another example appears at the State of Washington's Department of Ecology website (State of Washington 2010b). Table 19, taken from that website, lists the permits that a biodiesel manufacturer should consider; furthermore, the department notes that these are the commonly required permits but that the permits needed are not limited to those listed in the table. This qualification confirms the uncertainty inherent in the permitting process.

I.2.3 Land Use and Zoning in the Vicinity of Airports

Being a good neighbor is often a principle that airports adopt since it can enable a mutually beneficial relationship between airport operators and surrounding developments and avoid

Table 19. Examples of commonly required permits (State of Washington 2010b).

Jurisdiction	Type of Permit
City and county	• Building • Preliminary/final plat • Grading • Water system • Shoreline • Right of way • Utility • Site plan review • Septic system • Floodplain development • Variance (zoning, shoreline, etc.) • Outdoor burning
State	• Dept. of Fish and Wildlife ▪ Hydraulic project approval ▪ Bald eagle management ▪ Grass carp ▪ Shooting preserve • Dept. of Natural Resources ▪ Forest practices ▪ Aquatic lease ▪ Burning (forest slash) ▪ Reclamation • Dept. of Ecology ▪ Water rights ▪ Well drilling ▪ National Pollutant Discharge Elimination System (NPDES) ▪ Water quality certification ▪ Storm water ▪ Underground storage tank certification ▪ Dangerous waste • Air Authority/Dept. of Ecology ▪ New source review, for a business or industry ▪ Notice of intent, for demolition projects
Federal	• U.S. Army Corp of Engineers ▪ Section 10 (Navigable Waters) ▪ Section 404 (Fill in Waters) • U.S. Coast Guard ▪ Section 9 (Bridges) • National Marine Fisheries/U.S. Fish and Wildlife • Endangered Species Act consultation

potentially costly litigation. In order to avoid conflict with airport surroundings, land-use zoning must be done carefully in the areas near an airport.

In general, zoning rules and regulations vary considerably from one jurisdiction to another, and it is not practical to summarize them in this document. Airports should consult *ACRP Report 27: Enhancing Airport Land Use Compatibility* (Ward et al. 2010) for a deeper discussion of this topic. Nevertheless, there are a few general observations that can help airports evaluate alternative fuel projects with respect to zoning:

- **Obstacles to air navigation:** The FAA requires that there be no object, man-made or natural outgrowth, that is 200 ft from the ground level of the airport and within a 3-nautical-mile radius of the established reference point of the airport. Other requirements are listed in FAR Part 77.
- **Noise assessment:** If construction of alternative jet fuel facilities would require modifications to existing airspace procedures, a proper EIS is needed before the FAA could approve route changes when there is a significant noise impact on the affected population. See Section I.2.1 for more information on EISs.
- **Agricultural land near airports:** The FAA recommends against using airport property for agricultural production because agricultural crops can attract wildlife during some phase of production (FAA 1997b). If the airport requires agricultural crops as a means to produce income necessary for the viability of the airport, it needs to follow the crop-distance guidelines established in AC 150/5300-13, Appendix 17. Airports should be advised that the FAA may require a WHA or WHMP when specific triggering events occur on or near an airport, as specified in 14 CFR Part 139, Certification of Airports. Such events include an air carrier aircraft striking wildlife, an air carrier aircraft engine experiencing an engine ingestion of wildlife, or observing wildlife of a size or in numbers capable of causing an aircraft strike or engine ingestion. The WHA plan must be conducted by biologists with the appropriate training and education specified in AC 150/5200-36. Agricultural land use is compatible with airport operations from a noise sensitivity perspective (FAA 2001).

I.2.4 Additional Notes on Permitting

One significant risk with the permitting process is that it can stall a project's implementation or scuttle it entirely. Because of this risk, incorporating adequate lead time is absolutely necessary to meet all permitting requirements and not to incur delays in project coordination, planning, design, engineering, site preparation, construction, and inspection necessary for the development of alternative fuel infrastructure. Front-end planning for permitting with appropriate time buffers for areas of risk or uncertainty will allow for some flexibility in schedule adherence given the numerous permitting requirements that will inevitably vary with selection of a particular site.

This section has emphasized the motivation, complexity, and uncertainty associated with permitting. Because each alternative jet fuel facility carries its own risks, the permitting process is almost customized to each situation. Therefore, an airport that seeks to install alternative jet fuel facilities of any type should refer to a consultant with expertise in this matter and incorporate the recommendations into the project plan.

I.3 Energy Policy

Support for alternative jet fuel projects comes from various entities and policies, including the federal government and NGOs. This section summarizes some of the most visible entities and policies and indicates how they may be helpful to alternative jet fuel projects:

- **White House energy policy**
  The current administration in the White House has a policy framework that supports both biofuels production and the allocation of those funds to aviation fuel sources. These policies include but may not be limited to the following:
  - On May 5, 2009, the biofuels policy framework established the USDA's commitment to allocate funds to biofuels development. USDA announced its approach to meeting that commitment in June 2009 (USDA 2009).

- In February 2010, the Biofuels Interagency Working Group issued its report highlighting aviation fuel deployment. The report specifically calls for using pre-established market outlets and customer purchase commitments to stimulate production of feedstocks and biofuels (USDA 2010h).

- The FAA Office of Environment and Energy sets policy and offers programs to monetize the benefits of using alternative fuels. Relevant initiatives sponsored by this office include:
  - **Next Gen Environmental Working Group.** This group, part of JPDO, sets goals for carbon and particle emission reductions. As part of NextGen, FAA and project contributors have the objective of finding ways for aviation to grow without increasing its environmental impact. Much of the progress in quantifying the life-cycle carbon benefits of alternative fuel is a result of programs initiated to accommodate those goals.
  - **PARTNER Project 28: Environmental Cost-benefit Analysis of Alternative Jet Fuels.** This project quantifies aviation-specific GHG levels for a range of alternative fuel options that may be proposed for adoption by airports and their stakeholders (PARTNER 2010c). The analysis includes effects of land use (direct and indirect) and provides uncertainty bands to set the range of possibilities for outcomes.
  - **PARTNER Project 20: Emissions Characteristics of Alternative Aviation Fuels.** This project characterizes particle emission measurements for a series of alternative fuels (PARTNER 2010a).
  - **PARTNER Project 27: Environmental Cost-Benefit Analysis of Ultra Low Sulfur Jet Fuels.** This project established the health effects of particles for use in conjunction with the FAA's APMT suite (PARTNER 2010b).

The FAA has other programs that can be of interest to alternative aviation fuel projects. These include:

- **Voluntary Airport Low Emissions Program:** VALE was established in 2004 to help commercial service airports in designated air quality non-attainment and maintenance areas reduce airport ground emissions (FAA 2011b). VALE allows airport sponsors to use the AIP and PFCs to finance low-emission vehicles, refueling and recharging stations, gate electrification, and other airport air quality improvements. While VALE is restricted to ground emissions, it could still be helpful for alternative jet fuel projects. For example, airports that participate in VALE gain valuable experience structuring projects and handling alternative fuels that could be useful for alternative jet fuel projects. Furthermore, some stationary sources that contribute to ground emissions, such as back-up generators, could theoretically use alternative jet fuel.
- **Sustainable Master Plan Pilot Program:** This program was recently introduced by the FAA. Participants evaluate ways to make sustainability a core objective at every airport (FAA 2011a). The program funds long-range planning documents at 10 airports around the country. These documents, called Sustainable Master Plans and Sustainable Management Plans, will include initiatives for reducing environmental impacts, achieving economic benefits, and increasing airport integration with local communities. The program is projected to end in late 2012. This program may provide valuable information to airports interested in integrating alternative jet fuel projects into their sustainability initiatives.

- **Programs to fund studies and other nonrecurring investments in alternative fuels**

  The following programs exist at the federal, state, or local levels:
  - 2008 USDA Budget Authorization, section 9000 for renewable energy proposed rules associated with BCAP (USDA 2010c).
  - Federal and state policies and programs for rural renewable project evaluation and developments, such as value added grants and state enterprise grants (USDA 2010p; USDA 2010m).

- Organized state and local policies and coalitions to promote regional growth, for example the State of Georgia's Centers for Innovation (GCI 2011).
- Military Title III programs, which can enable initial plant construction for national defense priorities (Finnessy 2006).

- **Policies to allow recurring support for energy projects**

These policies can take a variety of forms, including tax incentives, insurance for crops, and tax credits for the alternative fuels. These programs exist at the federal, state, or local levels:

- Possible price supports for growers and price collars for buyers and sellers, similar to those available for food crops (USDA 2010k).
- Crop insurance similar to that available for food crops (USDA 2010f).
- DOD policies involving alternative fuel commitments, such as the plan to have 50% of continental U.S. military jet fuel consumption sourced from synthetic fuel blends (Andrews 2009).
- Tax credits, such as the one-dollar-per-gallon tax credit for biofuels (currently renewed on a year-by-year basis) (American Fuels 2010).

- **Nongovernmental, industry trade association stakeholder goals and policies**
  - IATA and its stated industry goal of carbon neutral growth by 2020 (IATA 2010).
  - Air Transport Association policy on alternative fuels (ATA 2010c).
  - ATA/AIA biofuel producer policy letter to President-Elect Obama (Altman 2010).
  - Airport associations, such as Airport Council International–North America sustainability and business policies (ACI–NA 2010).
  - Roundtable on Sustainable Biofuels best practices (RSB 2010).
  - Growers association policies and plans: Projects such as value-added grants need to be submitted for funding—in many cases through agricultural institutions. Therefore, the policies of these organizations are relevant for planning purposes. One example of this process is afforded by a proposal made via the Ohio Soybean Growers Association (OHSOY 2010) for a brownfield plant conversion to produce alternative jet fuel.
  - Environmental NGOs: Several environmental NGOs, such as the National Resources Defense Council and the World Wildlife Federation, have participated in alternative jet fuel forums at the request of CAAFI in the United States and SWAFEA in Europe.

- **Public/Private Partnerships and Coalitions**

Several organizations focused on the development and deployment of alternative jet fuels have been formed over the past few years. These include:

- **Commercial Aviation Alternative Fuels Initiative:** CAAFI is a coalition of government and private-sector organizations, including the FAA Office of Environment and Energy; AIA, representing manufacturers; ATA, representing airlines; and ACI–NA, representing airports (CAAFI 2010). CAAFI's 350 members represent nearly 250 separate entities, including some 17 U.S. government agencies. CAAFI is organized around four working groups covering qualification of fuels for safe use, environmental benefit calculation, research and development of all feedstocks and processes, and deployment. These working groups operate in concert with the ATA Energy Council of fuel buyers and some 50 energy company stakeholders. CAAFI seeks to facilitate deployment of alternative jet fuels, and its airline sponsor (ATA) has been involved with several ACRP problem statements related to alternative jet fuel.
- **ATA/Defense Energy Support Center Alliance:** In March 2010, ATA signed an agreement with the DLA (formerly DESC) to pursue joint policies for the purchase of alternative fuels. The alliance seeks to align purchasing policies, promote deployment, and pursue common economic policies (ATA 2010b).
- **Farm to Fly:** The Farm to Fly coalition of interest between the U.S. Department of Agriculture, the airline industry (ATA), and Boeing was formed in July 2010 as the result of dialog

between the Secretary of Agriculture and industry representatives (ATA 2010a). It specifically seeks to encourage deployment activity, initially working on bottom-up models for developing fuel supplies for aviation regions of the United States. The concept is beginning with studies in the Pacific Northwest and Hawaii.

- **Regional coalitions:** There are also regional initiatives focused on partnerships for the development of alternative fuel projects in specific geographic areas. Examples include the Georgia Center of Innovation for Energy (GCI 2011), the Hawaii Renewable Energy Alliance (HREA 2011), Clean Fuels Ohio (CFO 2011), and the Sustainable Aviation Fuels Northwest in the U.S. Pacific Northwest (SAFNW 2011a). SAFN just published a detailed report analyzing and evaluating the potential for alternative jet fuel production in their region (SAFNW 2011b).

APPENDIX J

Transportation and Logistics of Alternative Fuels

Drop-in alternative jet fuels will be able to share the same transportation, storage, and handling infrastructure as conventional jet fuel. Thus, from a logistical point of view, there should be no difference between alternative and conventional jet fuel. However, since jet fuel infrastructure is typically a shared resource serving many customers, all users must agree to the alternative jet fuel being present in the distribution chain.

The main options for transporting alternative or conventional jet fuel to the airport are listed in the following:

- **Pipeline:** This is the most cost-effective option for transporting the finished fuel, especially if the processing plant and the airport already have pipeline access.
- **Rail or barge:** Rail or barges are the next most cost-effective options for transporting finished fuel. As in the case of pipelines, the maximum benefit is achieved if both the processing plant and the airport already have access to rail or barges.
- **Truck:** This is the least cost-effective option for transporting the finished fuel; however, truck transportation provides the most flexibility because it does not require the existence of expensive infrastructure such as pipelines or railways. Thus, in the absence of pipelines or railways, truck transportation may be the most practical option.

One important consideration that should be highlighted is the potential need for blending infrastructure. Since thus far alternative jet fuels have only been certified as a blend (up to 50% in the case of FT), there will have to be a place in the supply chain, prior to reaching the wing of the aircraft, where alternative and petroleum-based jet fuels are blended. This will most likely consist of separate storage for conventional jet fuel, alternative jet fuel, and the blend. Logical locations for blending facilities are points along the supply chain where alternative and conventional fuel would intersect. For example, injection points at pipelines that transport jet fuel and airport fuel farms are likely locations.

APPENDIX K

Publicly Announced Aviation Alternative Fuel Projects

There have been several announcements of alternative jet fuel projects. These early projects are important because they demonstrate interest from several different stakeholders, including airports, airlines, and fuel producers, in this technology. While it is expected that the number of announced projects will increase over time, following is a representative sample of the type of projects that have been announced.

K.1 Rentech—Rialto

In the summer of 2009, Rentech, Inc., and Aircraft Service International Group (ASIG) made an agreement with eight airlines to produce 1.5 million gallons of renewable synthetic diesel fuel (RenDiesel) to support ground service equipment at LAX (ATA 2009b). The airlines that have partnered with Rentech are Alaska Airlines, American Airlines, Continental Airlines, Delta Air Lines, Southwest Airlines, United Airlines, UPS Airlines, and US Airways. Production of RenDiesel is planned to begin in 2012 at a facility in Rialto, CA. Primary feedstock will be urban woody green waste such as yard clippings.

K.2 Rentech—Natchez

Under the Natchez Project, Rentech, Inc., has made a nonbinding memorandum of understanding (MOU) with 13 airlines to produce 16,600 barrels of renewable synthetic jet fuel per day (Rentech 2010). The Natchez Project could potentially produce 400 million gallons of synthetic fuel per year. The airlines that have partnered with Rentech are Air Canada, AirTran Airways, American Airlines, Atlas Air, Delta Air Lines, FedEx Express, JetBlue Airways, Lufthansa German Airlines, Mexicana Airlines, Polar Air Cargo, United Airlines, UPS Airlines, and US Airways. The Natchez Project synthetic fuel production will be located at a 450-acre facility in Adams County, MS, near the city of Natchez. This facility will have access to many feedstocks, including petcoke and biomass, and several modes of distribution will be available.

K.3 Altair

Altair signed a MOU with 14 airlines to produce 75 million gallons of alternative jet fuel and diesel fuel per year (Heim 2009). The airlines that have partnered with Altair are Air Canada, American Airlines, Atlas Air, Delta Air Lines, FedEx Express, JetBlue Airways, Lufthansa German Airlines, Mexicana Airlines, Polar Air Cargo, United Airlines, UPS Airlines, US Airways, Alaska Airlines, and Hawaiian Airlines. Altair fuel production is planned to begin in the fourth

quarter of 2012 at the Tesoro refinery in Anacortes, WA (ATA 2009a). Altair's bio-jet fuel will be blended with petroleum-based jet fuel at the Tesoro refinery and piped to Seattle–Tacoma International Airport for use in aircraft and heavy machinery. The primary feedstock will be *Camelina* oil.

K.4 Solena

Solena Group, Inc., has partnered with British Airways PLC to produce 16 million gallons of jet fuel and diesel fuel per year for 10 years (Solena Group 2010). The location of biofuel production is still undecided, but will potentially be near Dagenham in east London. Construction should begin in 2011, and production is scheduled to begin mid-2014. The facility will reportedly be a waste-to-biofuels plant, using feedstocks such as plastics, paper, and food leftovers. British Airways hopes to recruit other airlines into this venture.

Glossary

Term	Definition
Alternative jet fuels	Combustible liquid fuels made from nonpetroleum sources that have the same performance characteristics in aircraft as today's commercial and military jet fuels.
ASTM International	Formerly known as the American Society for Testing and Materials, this organization is a globally recognized leader in the development and delivery of international voluntary consensus standards. More information at www.astm.org.
ASTM D1655	Standard specification for aviation turbine fuels according to ASTM International.
ASTM D7566	Standard specification for aviation turbine fuel containing synthesized hydrocarbons according to ASTM International. This was the first specification for alternative jet fuels approved by ASTM.
Air Transport Association (ATA)	The oldest and largest airline trade association in the United States. More information at www.airlines.org.
Bio-SPK	Synthetic paraffinic kerosene produced from bio-derived feedstocks.
Biomass	Any material produced by living or recently living organisms such as wood, leaves, seeds, and algae.
Catalytic to jet (CTJ)	Process that uses nonbiological agents that produce alcohols that can then be processed into alternative jet fuel.
Commercial Aviation Alternative Fuels Initiative	A coalition of airlines, aircraft and engine manufacturers, energy producers, researchers, international participants, and U.S. government agencies working to enhance energy security and environmental sustainability for aviation through alternative jet fuels. More information at www.caafi.org.
European Union Emissions Trading System	A cap-and-trade program to limit the total amount of certain greenhouse gases that can be emitted by different sources, including aircraft. More information at http://ec.europa.eu/clima/policies/ets/index_en.htm.

Term	Definition
Fischer-Tropsch (FT) process	A series of chemical reactions used to transform a carbon-rich feedstock, such as coal, natural gas, or biomass, into a hydrocarbon fuel such as jet fuel.
Fermentation to jet (FTJ)	Process that uses biological organisms that turn feedstocks directly into finished products such as alternative jet fuel.
Greenhouse gases	Gases in the atmosphere that absorb heat in the atmosphere. The primary greenhouse gases are water vapor, CO_2, methane (CH_4), NO_x, and ozone (O_3).
Hydroprocessed esters and fatty acids (HEFA)	Alternative fuel made from plant oils or animal fats through a series of chemical reactions, including hydroprocessing.
Life-cycle analysis (LCA)	An analysis technique for assessing environmental impacts associated with all the stages of a product's life. Life-cycle analysis as it applies to aviation fuel consists of estimating the amounts of various substances produced (or consumed) during the complete process of obtaining and using the fuel.
Life-cycle carbon footprint	Estimated carbon released in the life cycle (i.e., extraction of raw materials, processing, combustion, disposal) of a given material such as jet fuel.
Pyrolysis oil to jet (PTJ)	Process that converts cellulosic feedstocks into a bio-crude that can be used to produce alternative jet fuel.
Renewable Fuel Standards	Standards created under the Energy Policy Act of 2005 and expanded under the Energy Independent and Security Act of 2007. These standards establish renewable fuel volume mandates in the United States. More information at http://www.epa.gov/otaq/fuels/renewablefuels/index.htm.
Renewable Identification Number	A central component of the RFS program representing units of renewable fuel that can be used for credits, trading, and demonstrate compliance with renewable fuel mandates.

Acronyms and Abbreviations

Acronym/Abbreviation	Definition
AB32	Assembly Bill 32
ABFA	Advanced Biofuels Association
AC	Advisory Circulars
ACI–NA	Airport Council International–North America
ADO	Airport District Office
AIP	Airport Improvement Program
APMT	Aviation Portfolio Management Tool
ATA	Air Transport Association
BCAP	Biomass Crop Assistance Program
BD	Biodiesel
BFDP	Bioenergy Feedstock Development Program
BGTL	Biomass and gas to liquid
Bio-SPK	Bio-synthetic paraffinic kerosene
CAA	Clean Air Act
CAAFI	Commercial Aviation Alternative Fuels Initiative
CBTL	Coal and biomass to liquid
CCS	Carbon capture and sequestration
CTJ	Catalytic to jet
CTL	Coal to liquid
DLA	Defense Logistics Agency (formerly DESC)
DOD	Department of Defense
DOE	Department of Energy
EA	Environmental assessment
EIS	Environmental impact statement
EPA	Environmental Protection Agency

Acronym/Abbreviation	Definition
ERC	Emission reduction credit
ETS	Emissions trading scheme
EU	European Union
FAME	Fatty acid methyl ester
FAR	Federal aviation regulations
FTJ	Fermentation to jet
FT	Fischer-Tropsch
FT SPK	Fischer-Tropsch paraffinic kerosene
g CO_2e	Grams CO_2 equivalent
GHG	Greenhouse gas
GPY	Gallons per year
HECP	Herbaceous Energy Crops Program
HEFA	Hydroprocessed esters and fatty acids
HRJ	Hydrotreated renewable jet
ICAO	International Civil Aviation Organization
IMPLAN	Impact analysis for planning
JPDO	Joint Program Development Office
LCA	Life-cycle analysis
LPG	Liquefied petroleum gas
MGY	Million gallons per year
MJ	Megajoule
MOU	Memorandum of understanding
MSW	Municipal solid waste
NAA	Non-attainment areas
NAAQS	National Ambient Air Quality Standard
NABC	National Advanced Biofuels Consortium
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NGO	Nongovernmental organizations
NPDES	National Pollutant Discharge Elimination System
PARTNER	Partnership for Air Transportation Noise and Emission Reduction
PFC	Passenger facility charge
PTJ	Pyrolysis to jet

Acronym/Abbreviation	Definition
RFS	Renewable fuel standard
RGGI	Regional Greenhouse Gas Initiative
RIMS	Regional Input–Output Modeling System
RIN	Renewable Index Number
ROFA	Runway object free areas
RPZ	Runway protection zones
RSB	Roundtable on Sustainable Biofuels
SIP	State Implementation Plan
SPK	Synthetic paraffinic kerosene
SWAFEA	Sustainable Way for Alternative Fuel and Energy in Aviation
USAF	United States Air Force
USDA	U.S. Department of Agriculture
VALE	Voluntary Airport Low Emissions program
VOC	Volatile organic compounds
WHA	Wildlife hazard assessment
WHMP	Wildlife hazard management plan

References

ABFA. 2011. Advanced Biofuels Association home page. http://www.advancedbiofuelsassociation.com/ (access date June 26, 2011).

ACI–NA. 2010. Sustainable Aviation. Airports Council International–North America. http://www.aci-na.org/sustainability/index.html (access date November 19, 2010).

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Mantague, A. Slayton, and J. Lukas. 2002. *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover.* U.S. Department of Energy, National Renewable Energy Laboratory, Report number NREL/TP-510-32438. http://www.osti.gov/bridge/product.biblio.jsp?query_id=2&page=0&osti_id=15001119 (access date November 17, 2010).

Advanced Biofuels. 2009. Amyris, GE, and Embraer Partner to Test Sugarcane Jet Fuel in Azul Airlines Jet By 2012. *Biofuels Journal.* http://www.biofuelsjournal.com/info/bf_articles.html?ID=85663 (access date July 7, 2011).

Aeromexico. 2011. *Aeromexico, ASA, and Boeing Announce the First Transcontinental Flight in Aviation History to Use Biofuel.* http://www.aeromexico.com/us/ExperienceAeromexico/AeromexicoCorporate/PressRoom/Green-flight.html (access date October 11, 2011).

Airbus. 2011. Alternative Fuels. http://www.airbus.com/innovation/eco-efficiency/operations/alternative-fuels/ (access date July 7, 2011).

Al-Zuhair, S. 2007. "Production of Biodiesel: Possibilities and Challenges." *Biofuels, Bioproducts and Biorefining,* Vol. 1, No. 1, 57–66. http://onlinelibrary.wiley.com/doi/10.1002/bbb.2/pdf (access date November 1, 2010).

Allen, T. D., C. Allport, K. Atkins, S. J. Cooper, M. R. Dilmore, C. L. Draucker, E. K. Eickmann, C. J. Gillen, W. Gillette, M. W. Griffin, E. W. Harrison III, I. J. Hileman, R. J. Ingham, A. F. Kimler III, A. Levy, F. C. Murphy, J. M. O'Donnell, D. Pamplin, G. Schivley, J. T. Skone, M. S. Strank, W. R. Stratton, H. P. Taylor, M. V. Thomas, Q. M. Wang, and T. Zidow. 2009. *Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels.* Air Force Research Laboratory, Report No. AFRL-RZ-WP-TR-2009-2206. http://www.netl.doe.gov/energy-analyses/pubs/EstGHGFtprntsAvFuels2009.pdf (access date November 15, 2010).

Altman, R. 2010. The Cost of Cleaner Aviation . . . The Alternative Fuels Opportunity. Commercial Aviation Alternative Fuels Initiative, Presentation to Transportation Research Board AV030/AV040 Committee Workshop. http://www.trbav030.org/pdf2010/Altman_cleaner_aviation.pdf (access date November 11, 2010).

American Fuels. 2010. Biodiesel Tax Credit Approved. http://americanfuels.blogspot.com/2010/07/biodiesel-tax-credit-approved.html (access date November 12, 2010).

Andrews, A. 2009. *Department of Defense Fuel Spending, Supply, Acquisition, and Policy.* Congressional Research Service. http://www.fas.org/sgp/crs/natsec/R40459.pdf (access date November 5, 2010).

Anumakonda, A. 2010. "Greening Global Aviation." Paper presented at MRO Americas, Phoenix, AZ.

ATA. 2009a. "Additional Details for Airlines Alternative Fuel Development News Release." Air Transport Association. http://airlines.org/News/Releases/Pages/news_12-15-09b.aspx (access date November 15, 2010).

ATA. 2009b. "Airlines Sign First-of-Its-Kind Ongoing Supply Agreement with Rentech and ASIG For Renewable Synthetic Diesel Fuel to Be Used in LAX Ground Service Equipment." Air Transport Association. http://www.airlines.org/News/Releases/Pages/news_8-18-09.aspx (access date November 15, 2010).

ATA. 2009c. Standard for Jet Fuel Quality Control at Airports. Air Transport Association, Standard Spec 103. https://publications.airlines.org/CommerceProductDetail.aspx?Product=82.

ATA. 2010a. "ATA Announces Formation of 'Farm to Fly' Sustainable Aviation Biofuels Initiative." Air Transport Association. http://www.airlines.org/News/Releases/Pages/News_07-21-10.aspx (access date November 11, 2010).

ATA. 2010b. "ATA/DESC Announce Strategic Alliance for Alternative Aviation Fuels." Air Transport Association. http://www.airlines.org/News/Releases/Pages/news_3-19-10.aspx (access date November 11, 2010).

ATA. 2010c. Commercial Aviation Alternative Fuels: The ATA Commitment. Air Transport Association. http://www.airlines.org/Environment/AlternativeFuels/Pages/CommercialAviationAlternativeFuelsTheATACommitment.aspx (access date November 11, 2010).

Baffes, J. and T. Haniotis. 2010. *Placing the 2006/08 Commodity Price Boom into Perspective.* The World Bank, Report number WPS5371. http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2010/07/21/000158349_20100721110120/Rendered/PDF/WPS5371.pdf.

Bauen, A., J. Howes, L. Bertuccioli and C. Chudziak. 2009. *Review of the Potential for Biofuels in Aviation.* E4tech for the Committee on Climate Change. http://downloads.theccc.org.uk/Aviation%20Report%2009/E4tech%20(2009),%20Review%20of%20the%20potential%20for%20biofuels%20in%20aviation.pdf (access date November 4, 2010).

Beyersdorf, A. and B. Anderson. 2009. "An Overview of the NASA Alternative Aviation Fuel Experiment (AAFEX)." *Second International Conference on Transport, Atmosphere and Climate (TAC-2) Proceedings,* Aachen and Maastricht, The Netherlands. June 22–25, 2009. http://www.pa.op.dlr.de/tac/2009/proceedings/021-032.pdf (access date November 16, 2010).

Bombardier. 2010. Bombardier Q400 Aircraft Operated by Porter Airlines to be Flown in Biofuel Test Program. Bombardier. http://www.bombardier.com/en/aerospace/media-centre/press-releases/details?docID=0901260d8011f822 (access date July 7, 2011).

Bowen, B. H. and M. W. Irwin. 2007. Coal Transportation Economics. The Energy Center and Discovery Park, Purdue University, CCTR Basic Facts File #7. http://www.purdue.edu/discoverypark/energy/pdfs/cctr/outreach/Basics7-Transportation-Apr07.pdf (access date November 15, 2010).

Brandes, R. 2007. *U.S. EPA Waste Management Perspective: The Need for Integrated Materials Management.* U.S. Environmental Protection Agency, Office of Solid Waste. http://www.frederickcountymd.gov/documents/Board%20of%20County%20Commissioners/Solid%20Waste%20Forum%202007/Rick%20Brandes%20EPA%20Presentation.pdf (access date November 19, 2010).

Brechbill, S. C. and W. E. Tyner. 2008. *The Economics of Biomass Collection, Transportation, and Supply to Indiana Cellulosic and Electric Utility Facilities.* Purdue University, Department of Agricultural Economics, Working Paper 08-03. http://ageconsearch.umn.edu/bitstream/6148/2/wp080003.pdf (access date November 17, 2010).

Brown, L. 2007. "Massive Diversion of U.S. Grain to Fuel Cars is Raising World Food Prices." Earth Policy Institute. http://www.earth-policy.org/index.php?/plan_b_updates/2007/update65 (access date June 24, 2011).

Busby, D., R. D. Little, S. Shaik, A. Martins, F. Epplin, S. Hwang, B. S. Baldwin, and C. M. Taliaferro. 2007. "Yield and Production Costs for Three Potential Dedicated Energy Crops in Mississippi and Oklahoma Environments." Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Mobile, Alabama, February 2007. http://ageconsearch.umn.edu/bitstream/34854/1/sp07bu07.pdf (access date November 2, 2010).

CAAFI. 2010. Commercial Aviation Alternative Fuels Initiative. http://www.caafi.org/ (access date November 12, 2010).

CAEPA. 2009. Facts about Assembly Bill 32 Global Warming Solutions Act. California Environmental Protection Agency. http://www.arb.ca.gov/cc/factsheets/ab32factsheet.pdf (access date November 5, 2010).

Canakci, M. and H. Sanli. 2008. "Biodiesel Production from Various Feedstocks and Their Effects on the Fuel Properties." *Journal of Industrial Microbiology and Biotechnology,* Vol. 35, 431–441.

Carolan, J. E., S. V. Joshi, and B. E. Dale. 2007. "Technical and Financial Feasibility Analysis of Distributed Bioprocessing Using Regional Biomass Pre-Processing Centers." *Journal of Agricultural and Food Industrial Organization,* Vol. 5, No. 2. http://www.bepress.com/jafio/vol5/iss2/art10/ (access date November 17, 2010).

Carriquiry, M. and B. A. Babcock. 2008. "A Billion Gallons of Biodiesel: Who Benefits?" *Iowa Ag Review,* Vol. 14, No. 1, 6–8.

CFO. 2011. Clean Fuels Ohio home page. http://www.cleanfuelsohio.org/ (access date July 7, 2011).

Chatzis, N. 2011. A Real Environmental Innovation Challenge: Boeing Flies 747-8 Freighter to the Paris Air Show on a Fuel Blend of 15 Percent *Camelina*-Based Biofuel. Global News Pointer. http://www.globalnews-pointer.net/?p=1122 (access date July 7, 2011).

Corporan, E., M. J. DeWitt, V. Belovich, R. Pawlik, A. C. Lynch, J. R. Gord, and T. R. Meyer. 2007. "Emissions Characteristics of a Turbine Engine and Research Combustor Burning a Fischer–Tropsch Jet Fuel." *Energy Fuels,* Vol. 21, No. 5, 2615–2626.

CRB. 2008. Tallow and Greases. Commodity Research Bureau. http://www.crbtrader.com/fund/articles/tallow.asp (access date November 17, 2010).

Dale, B. E., B. D. Bals, S. Kim, and P. Erank. 2010. "Biofuels Done Right: Land Efficient Animal Feeds Enable Large Environmental and Energy Benefits." *Environmental Science and Technology,* Vol. 44, No. 22, 8385–8389. http://pubs.acs.org/doi/full/10.1021/es101864b.

DOC. 2011. List of Federal and State Incentives Program for the Development of Alternative Fuels. Department of Commerce. http://trade.gov/mas/manufacturing/OAAI/aero_links_altfuels.asp (access date March 3, 2011).

DOE. 2003. Roadmap for Agricultural Biomass Feedstock Supply in the United States. U.S. Department of Energy. http://www.inl.gov/technicalpublications/Documents/3323197.pdf (access date November 22, 2010).

DOE. 2009. Three More Airlines Complete Test Flights Using Biofuels. U.S. Department of Energy. http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=12219 (access date July 7, 2011).

DOE. 2010. National Algal Biofuels Technology Roadmap. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf (access date November 1, 2010).

DOE. 2011a. Enhanced Oil Recovery/CO_2 Injection. U.S. Department of Energy. http://fossil.energy.gov/programs/oilgas/eor/ (access date July 7, 2011).

DOE. 2011b. Federal & State Incentives & Laws. U.S. Department of Energy. http://www.afdc.energy.gov/afdc/laws/ (access date March 3, 2011).

EC. 2003. Establishing a Scheme For Greenhouse Gas Emission Allowance Trading Within the Community and Amending Council Directive 96/61/EC. European Commission. Directive 2003/87/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:275:0032:0046:en:pdf (access date December 20, 2010).

EC. 2010. Emissions Trading System (EU ETS). European Commission. http://ec.europa.eu/clima/policies/ets/index_en.htm (access date December 20, 2010).

EIA. 2010. Delivery and Storage of Natural Gas. U.S. Energy Information Administration. http://tonto.eia.doe.gov/energyexplained/index.cfm?page=natural_gas_delivery (access date November 22, 2010).

EIA. 2011. Ranking of U.S. Refineries. U.S. Energy Information Administration. http://www.eia.doe.gov/neic/rankings/refineries.htm (access date June 27, 2011).

Eidman, V. R. 2007. "Economic Parameters for Corn Ethanol and Biodiesel Production." *Journal of Agricultural and Applied Economics,* Vol. 39, No. 2, 345–356.

EPA. 1990. Clean Air Act. Environmental Protection Agency. http://www.epa.gov/air/caa/ (access date December 20, 2010).

EPA. 1999. *Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft.* Environmental Protection Agency. Report EPA420-R-99-013. http://www.epa.gov/oms/regs/nonroad/aviation/r99013.pdf (access date November 21, 2010).

EPA. 2010a. Acid Rain Program. Environmental Protection Agency. http://www.epa.gov/airmarkets/progsregs/arp/index.html (access date November 21, 2010).

EPA. 2010b. Clean Air Markets. Environmental Protection Agency. http://www.epa.gov/airmarkets/ (access date November 21, 2010).

EPA. 2010c. *EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond.* Environmental Protection Agency. Report EPA-420-F-10-007. http://www.epa.gov/oms/renewablefuels/420f10007.htm (access date November 5, 2010).

EPA. 2010d. NO_x Budget Trading Program. Environmental Protection Agency. http://www.epa.gov/airmarkets/progsregs/nox/sip.html (access date November 21, 2010).

EPA. 2010e. Obama Announces Steps to Boost Biofuels, Clean Coal. News Releases Issued by the Office of Air and Radiation. http://yosemite.epa.gov/opa/admpress.nsf/7ebdf4d0b217978b852573590040443a/3a91d20f44b4b2d2852576bf00711782!OpenDocument (access date November 21, 2010).

EPA. 2011. PM Standards. Environmental Protection Agency. http://www.epa.gov/air/particlepollution/standards.html (access date June 24, 2011).

FAA. 1989. Airport Design. Federal Aviation Administration. AC 150/5300-13. http://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5300_13.pdf (access date December 20, 2010).

FAA. 1993. Federal Aviation Regulations, Part 77, Objections Affecting Navigable Airspace. Federal Aviation Administration. https://oeaaa.faa.gov/oeaaa/external/content/FAR_Part77.pdf (access date December 20, 2010).

FAA. 1997a. *Air Quality Procedures for Civilian Airports and Air Force Bases.* Federal Aviation Administration. Report FAA-AEE-97-03. http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/media/Handbook.pdf (access date December 20, 2010).

FAA. 1997b. Hazardous Wildlife Attractants On or Near Airports. Federal Aviation Administration. AC 150/5200-33. http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/53bdbf1c5aa1083986256c690074ebab/$FILE/150-5200-33.pdf (access date November 21, 2010).

FAA. 2001. Land Use Compatibility and Airports. Federal Aviation Administration. http://www.faa.gov/about/office_org/headquarters_offices/aep/planning_toolkit/media/III.B.pdf (access date November 16, 2010).

FAA. 2004. Aircraft Fuel Storage, Handling, and Dispensing on Airports. Federal Aviation Administration. AC 150/5230-4A. http://www.faa.gov/documentLibrary/media/advisory_circular/150-5230-4A/150_5230_4a.pdf (access date December 20, 2010).

FAA. 2005a. Airport Grant Assurance Compliance Certification. Federal Aviation Administration. Form ANM 620agaacc. http://www.faa.gov/airports/northwest_mountain/airports_resources/forms/media/compliance/compliance_certification_form.doc (access date November 21, 2010).

FAA. 2005b. *Airport Improvement Program Handbook.* Federal Aviation Administration. Order 5100.38.C. http://www.faa.gov/airports/resources/publications/orders/media/aip_5100_38c.pdf (access date November 5, 2010).

FAA. 2005c. Airport Sponsor Assurances. Federal Aviation Administration. http://www.faa.gov/airports/aip/grant_assurances/media/airport_sponsor_assurances.pdf (access date November 21, 2010).

FAA. 2006a. Minimum Standards for Commercial Aeronautical Activity. Federal Aviation Administration. AC 150/5190-7. http://www.faa.gov/documentLibrary/media/advisory_circular/150-5190-7/150_5190_7.pdf (access date November 21, 2010).

FAA. 2006b. National Environmental Policy Act (NEPA) Implementing Instructions for Airport Projects. Federal Aviation Administration. Order 5050.4B. http://www.faa.gov/airports/resources/publications/orders/environmental_5050_4/ (access date December 20, 2010).

FAA. 2007. *Environmental Desk Reference for Airport Actions.* Federal Aviation Administration. http://www.faa.gov/airports/environmental/environmental_desk_ref/media/desk_ref.pdf (access date June 27, 2011).

FAA. 2009. "Appendix R, Airport Layout Plan." In *FAA Airport Compliance Manual.* Federal Aviation Administration. Order 5190.6B. http://www.faa.gov/airports/resources/publications/orders/compliance_5190_6/media/5190_6b_appR.pdf (access date December 20, 2010).

FAA. 2010a. Approval of Propulsion Fuels and Lubricating Oils. Federal Aviation Administration. AC 20-24C. http://www.faa.gov/AIRCRAFT/DRAFT_DOCS/media/DraftAC20_24C.doc (access date November 4, 2010).

FAA. 2010b. Revenue Producing Facility Policy. Federal Aviation Administration. http://www.faa.gov/airports/central/aip/revenue_producers/ (access date November 21, 2010).

FAA. 2011a. Airport Sustainability. Federal Aviation Administration. http://www.faa.gov/airports/environmental/sustainability/ (access date June 27, 2011).

FAA. 2011b. Voluntary Airport Low Emissions Program (VALE). Federal Aviation Administration. http://www.faa.gov/airports/environmental/vale/ (access date June 27, 2011).

FAO. 2009. *Jatropha*—A Bioenergy Crop for the Poor. Food and Agriculture Organization of the United Nations. http://www.fao.org/news/story/en/item/44142/icode/.

Finnessy, T. 2006. "The Story on Title III." 2006 Wire Development Workshop, St. Petersburg, FL, January 31–February 1. http://theeestory.com/files/finnessy.pdf (access date November 11, 2010).

Flanders, A., A. L. Morgan, G. Shumaker, and J. McKissick. 2007. "Economic Impacts of Ethanol Production in Georgia." Association Annual Meeting, Southern Agricultural Economics, Mobile, AL, February 4–6.

Food Science Australia. 1997. Meat Technology Information Sheet—Tallow. Australian Commonwealth Scientific and Industrial Research Organisation. http://www.redmeatinnovation.com.au/innovation-areas/value-adding/co-products/mla-newsletters/tallow (access date November 21, 2010).

Gallagher, P. W. 2006. "Energy Production with Biomass: What are the Prospects?" *Choices,* Vol. 21, No. 1, 21–25.

GCI. 2011. Georgia Centers of Innovation home page. http://www.georgiainnovation.org/ (access date July 7, 2011).

Gross, S. 2011. Honeywell Green Jet Fuel™ Powers Demonstration Flight With Mexico's Interjet. Honeywell International, Inc. http://honeywell.com/News/Pages/4.1.11-Honeywell-Green-Jet-Fueltm-Powers-Demonstration-Flight-With-Mexico%E2%80%99s-Interjet.aspx (access date July 7, 2011).

Heim, K. 2009. "Seattle Startup Gets 14 Airlines to Sign on to Biofuel Agreement." *The Seattle Times.* http://seattletimes.nwsource.com/html/businesstechnology/2010516458_biofuel16.html (access date November 21, 2010).

Herzog, H. J. and D. Golomb. 2004. "Carbon Capture and Storage from Fossil Fuel Use." In *Encyclopedia of Energy.* C. J. Cleveland, ed. New York: Elsevier Science Inc., 277–287.

Hess, J., C. T. Wright, and K. L. Kenney. 2007. "Cellulosic Biomass Feedstocks and Logistics for Ethanol Production." *Biofuels, Bioproducts and Biorefining,* Vol. 1, 181–190. https://inlportal.inl.gov/portal/server.pt/gateway/PTARGS_0_2_12163_0_0_18/fulltext.pdf (access date November 21, 2010).

Hileman, J., D. Ortiz, J. Bartis, H. Wong, P. Donohoo, M. Weiss, and I. Waitz. 2009. Near Term Feasibility of Alternative Jet Fuel. PARTNER Project 28, PARTNER-COE-2009-001. http://web.mit.edu/aeroastro/partner/reports/proj17/altfuelfeasrpt.pdf (access date November 21, 2010).

Hodur, N. M., F. L. Leistritz, and T. Hertsgaard. 2006. "Contribution of the North Dakota Agricultural Products Utilization Commission Programs to the State Economy." North Dakota State University Department of Agribusiness and Applied Economics, Staff Paper No. AAE 06006. http://ageconsearch.umn.edu/handle/23653 (access date November 22, 2010).

HREA. 2011. Hawaii Renewable Energy Alliance home page. http://hawaiirenewableenergy.org/ (access date July 7, 2011).

IATA. 2009. *IATA Alternative Fuels Report.* International Air Transport Association. http://www.iata.org/SiteCollectionDocuments/Documents/IATA2009ReportonAlternativeFuelsonlineversion.pdf (access date November 22, 2010).

IATA. 2010. Fact Sheet: Carbon-Neutral Growth. International Air Transport Association. http://www.iata.org/pressroom/facts_figures/fact_sheets/Pages/carbon-neutral.aspx (access date November 22, 2010).

Inman, D., N. Nagle, J. Jacobson, E. Searcy, and A. E. Ray. 2010. "Feedstock Handling and Processing Effects on Biochemical Conversion to Biofuels." *Biofuels, Bioproducts and Biorefining*, Vol. 4, No. 5, 562–573. http://onlinelibrary.wiley.com/doi/10.1002/bbb.241/abstract (access date November 22, 2010).

Kalnes, T. N., M. M. McCall, and D. R. Shonnard. 2010. "Renewable Diesel and Jet-Fuel Production from Fats and Oils." In *Thermochemical Conversion of Biomass to Liquid Fuels and Chemicals*. M. Crocker, ed. London: Royal Society of Chemistry.

Karlsson, J., J. R. Ludders, D. Wilde, D. Mochrie, and C. Seymour. 2008. *ACRP Synthesis 7: Airport Economic Impact Methods and Models*. Transportation Research Board of the National Academies, Washington, D.C. http://onlinepubs.trb.org/onlinepubs/acrp/acrp_syn_007.pdf.

Karp, A. 2010. "TAM, Airbus Conduct A320 Test Flight Using *Jatropha*-Derived Fuel." *Air Transport World*. http://atwonline.com/eco-aviation/news/tam-airbus-conduct-a320-test-flight-using-jatropha-derived-fuel-1123 (access date July 7, 2011).

Khanna, M., B. Dhungana, and J. Clifton-Brown. 2008. "Costs of Producing *Miscanthus* and Switchgrass for Bioenergy in Illinois." *Biomass and Bioenergy*, Vol. 32, 482–493.

KLM. 2011. *KLM Launches Commercial Flights Amsterdam—Paris on biofuel*. KLM Royal Dutch Airlines. http://www.klm.com/corporate/en/newsroom/press-releases/archive-2011/KLM_launches_commercial_flights_Amsterdam.html (access date October 11, 2011).

Knothe, G. 2010. "Biodiesel: Current Trends and Properties." *Topics in Catalysis*, Vol. 53, 714–720.

Kuhn, M. 2009. "United Leads Airline Initiative to Support Synthetic Fuel Production Plant." *Flightglobal*. http://www.flightglobal.com/articles/2009/02/12/322470/united-leads-airline-initiative-to-support-synthetic-fuel-production.html (access date July 7, 2011).

Kumar, A. and S. Sokhansanj. 2007. "Switchgrass (*Panicum virgatum*, L.) Delivery to a Biorefinery Using Integrated Biomass Supply Analysis and Logistics (IBSAL) Model." *Bioresource Technology*, Vol. 98, No. 5 (March), 1033–1044.

Lane, J. 2010. "Pulp Non-Fiction: Biofuels a Ray of Sunshine in a Gloomy Season." *Biofuels Digest*. http://biofuelsdigest.com/bdigest/2011/02/18/pulp-non-fiction-biofuels-a-ray-of-sunshine-in-a-gloomy-season/ (access date June 27, 2010).

Lane, J. 2011. Honeywell to Attempt First Transatlantic Biofuels Flight. *Biofuels Digest*. http://biofuelsdigest.com/bdigest/2011/06/17/honeywell-to-attempt-first-transatlantic-biofuels-flight/ (access date July 7, 2011).

Lazarus, W. F. 2008. "Energy Crop Production Costs and Breakeven Prices Under Minnesota Conditions." University of Minnesota Department of Applied Economics, Staff Paper P08-11. http://ageconsearch.umn.edu/handle/45655 (access date November 22, 2010).

Leistritz, F. L. 2003. "Measuring the Economic Impact of Producer Cooperatives." In *Cooperatives and Local Development: Theory and Applications for the 21st Century*. C. D. Merritt and N. Walzer, eds. Armonk, NY: M. E. Sharp, 247–261.

Leistritz, F. L., D. A. Bangsund, N. M. Hodur, and D. M. Senechal. 2009. Factors Affecting Agricultural Biomass Supply. North Dakota Industrial Commission, R001-003. http://www.nd.gov/ndic/renew-project.htm.

Lewandowski, I., J. M. O. Scurlock, E. Lindvall, and M. Christou. 2003. "The Development and Current Status of Perennial Rhizomatous Grasses as Energy Crops in the U.S. and Europe." *Biomass and Bioenergy*, Vol. 25, 335–361.

Low, S. A. and A. M. Isserman. 2008. "Ethanol: Implications for Rural Communities." 2008 Annual Meeting, Agricultural and Applied Economics Association. Orlando, FL. July 27–29. http://ageconsearch.umn.edu/handle/6157 (access date November 22, 2010).

MacDonald, J. M. and P. Korb. 2011. "Agricultural Contracting Update: Contracts in 2008." Economic Information Bulletin No. 72. U.S. Department of Agriculture. http://ageconsearch.umn.edu/handle/101279.

Mapemba, L. D., F. Epplin, C. M. Taliaferro, and R. L. Huhnke. 2007. "Biorefinery Feedstock Production on Conservation Reserve Program Land." *Review of Agricultural Economics*, Vol. 29, No. 2, 227–246. http://econpapers.repec.org/article/blaragrec/v_3a29_3ay_3a2007_3ai_3a2_3ap_3a227-246.htm (access date November 22, 2010).

Mark, T., P. Darby, and M. Salassi. 2010. "What Does the Introduction of Energy Crops Mean for the Crop Mix and Cellulosic Ethanol Plant Location in Louisiana?" Annual Meeting, Southern Agricultural Economics Association. Orlando, FL. February 6–9. http://ageconsearch.umn.edu/bitstream/56543/2/What%20does%20the%20introduction%20of%20energy%20crops%20mean%20for%20the%20crop%20mix%20and%20cellulosic%20ethanol%20plant%20location%20in%20Louisiana_tm_1_14_10.pdf (access date November 1, 2010).

Maung, T. A. and B. A. McCarl. 2008. "Economics of Biomass Fuels for Electricity Production: A Case Study with Crop Residues." Annual Meeting, American Agricultural Economics Association. Orlando, FL. July 27–29. http://ageconsearch.umn.edu/bitstream/6417/2/467464.pdf (access date November 1, 2010).

Mecham, M. 2008. "JAL Sets Biofuel Test Flight Using *Camelina*." *Aviation Week*. http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=comm&id=news/CAMEL12168.xml&headline=JAL%20Sets%20Biofuel%20Test%20Flight%20Using%20Camelina (access date July 7, 2011).

Milbrandt, A. 2005. *A Geographic Perspective on the Current Biomass Resource Availability in the United States.* National Renewable Energy Laboratory, NREL/TP-560-39181.

MIT. 2011. Carbon Capture and Sequestration Technologies. Massachusetts Institute of Technology. http://sequestration.mit.edu.

Morser, F., P. Soucacos, J. I. Hileman, P. Donohoo, and S. Webb. 2011. *ACRP Report 46: Handbook for Analyzing the Costs and Benefits of Alternative Aviation Turbine Engine Fuels at Airports.* Transportation Research Board of the National Academies, Washington, D.C.

Moser, B. R. 2009. "Biodiesel Production, Properties, and Feedstocks." *In Vitro Cellular & Developmental Biology—Plant*, Vol. 45, No. 3, 229–266.

Moses, C. 2008. *Comparative Evaluation of Semi-synthetic Jet Fuels.* Coordinating Research Council, Inc. http://www.crcao.com/reports/recentstudies2008/AV-2-04a/AV-2-04a%20-%20Comparison%20of%20SSJF%20-%20CRC%20Final.pdf (access date July 7, 2011).

Mroue, M. 2011. Biofuel Transported Passengers Surely and More Sustainably. Finnair. http://blogs.finnair.com/2011/07/22/biofuels-transports-passengers-surely-and-sustainably/ (access date October 11, 2011).

NABC. 2010. National Advanced Biofuels Consortium Process Strategies. National Advanced Biofuels Consortium. http://www.nabcprojects.org/process_strategies.html (access date November 22, 2010).

Naik, S. N., V. V. Goud, P. K. Route, and A. K. Dalai. 2010. "Production of First and Second Generation Biofuels: A Comprehensive Review." *Renewable and Sustainable Energy Reviews,* Vol. 14, No. 2, 578–597.

Natural Gas Supply Association. 2010. Natural Gas Distribution. http://www.naturalgas.org/naturalgas/distribution.asp (access date November 22, 2010).

NETL. 2008. *Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels.* National Energy Technology Laboratory. DOE/NETL-2009/1346. http://www.netl.doe.gov/energy-analyses/pubs/NETL%20LCA%20Petroleum-based%20Fuels%20Nov%202008.pdf (access date November 22, 2010).

NETL. 2011. Technologies: Carbon Sequestration. National Energy Technology Laboratory. http://www.netl.doe.gov/technologies/carbon_seq/index.html (access date June 27, 2011).

Neumann, A. and C. von Hirschhausen. 2005. "Long-Term Contracts for Natural Gas: An Empirical Analysis." 9th ISNIE Conference, International Society for New Institutional Economics, Barcelona, Spain, September 22–24, 2005.

NFPA. 2007. Standard for Aircraft Fuel Servicing. National Fire Protection Association, NFPA 407. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=407&cookie_test=1 (access date December 20, 2010).

Ng, J. H., H. K. Ng, and S. Gan. 2009. "Recent Trends in Policies, Socioeconomy and Future Directions of the Biodiesel Industry." *Clean Technologies and Environmental Policy,* Vol. 12, 213–238.

North Sea Group. 2011. Biofuels. http://www.northseagroup.com/en/responsibility/biofuels (access date July 7, 2011).

Nyren, P. E., E. Eriksmoen, G. Bradbury, M. Halverson, E. Aberle, K. Nichols, and M. Liebig. 2007. The Evaluation of Selected Perennial Grasses for Biofuel Production in Central and Western North Dakota. North Dakota State University Central Grasslands Research Extension Center. http://www.ag.ndsu.edu/archive/streeter/2007report/Grasses_Biofuel.htm (access date November 22, 2010).

OHSOY. 2010. Ohio Soybean Growers Association home page. http://associationdatabase.com/aws/OHSOY/pt/sp/Home_Page (access date November 12, 2010).

Olson, F. Personal communication. Assistant Professor and Crops Economist, Department of Agribusiness and Applied Economics, North Dakota State University.

PARTNER. 2010a. Project 20—Emissions Characteristics of Alternative Aviation Fuels. Partnership for AiR Transportation Noise and Emissions Research. http://web.mit.edu/aeroastro/partner/projects/project20.html (access date November 5, 2010).

PARTNER. 2010b. Project 27—Environmental Cost-Benefit Analysis of Ultra Low Sulfur Jet Fuels. Partnership for AiR Transportation Noise and Emissions Research. http://web.mit.edu/aeroastro/partner/projects/project27.html (access date November 5, 2010).

PARTNER. 2010c. Project 28—Environmental Cost-Benefit Analysis of Alternative Jet Fuels. Partnership for AiR Transportation Noise and Emissions Research. http://web.mit.edu/aeroastro/partner/projects/project28.html (access date November 5, 2010).

Paulson, N. D. and R. G. Ginder. 2007. "The Growth and Direction of the Biodiesel Industry in the United States." Center for Agricultural and Rural Development, Iowa State University, Working Paper 07-WP 448. http://www.card.iastate.edu/publications/DBS/PDFFiles/07wp448.pdf (access date November 10, 2010).

Perlack, R. D., L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach. 2005. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply.* U.S. Department of Energy. http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf (access date November 1, 2010).

Peters, D. J. 2007. *The Economic Impact of Ethanol Production in Hall County.* University of Nebraska, Agricultural Economics Department, RD-2007-05-1. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1064&context=ageconfacpub (access date November 22, 2010).

Petrolia, D. R. 2008. "The Economics of Harvesting and Transporting Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota." *Biomass and Bioenergy,* Vol. 32, No. 7 (July), 603–612. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V22-4RR20Y5-1&_user=10&_coverDate=07%2F31%2F2008&_rdoc=1&_fmt=high&_orig=search&_origin=search&_sort=d&_docanchor=&view=c&_searchStrId=1551255979&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=14429df7a05ae8510e8c79b9cb9c8bc9&searchtype=a (access date November 22, 2010).

Qatar Airways. 2011. Alternative Fuels. Qatar Airways. http://www.qatarairways.com/global/en/csr-fuel.html (access date July 7, 2011).

Qiang, L., W. Du, and D. Liu. 2008. "Perspectives of Microbial Oils for Biodiesel Production." *Applied Microbiology and Biotechnology,* Vol. 80. 749–756.

Reals, K. 2011. "Lufthansa Biofuel Flights Postponed by Certification Delay." *Flightglobal.* http://www.flightglobal.com/articles/2011/02/18/353313/lufthansa-biofuel-flights-postponed-by-certification.html (access date July 7, 2011).

Rentech. 2010. Natchez Project. http://www.rentechinc.com/natchez.php (access date November 22, 2010).

Rentizelas, A. A., A. J. Tolis, and I. P. Tatsiopoulos. 2009. "Logistics Issues of Biomass: The Storage Problem and the Multi-biomass Supply Chain." *Renewable and Sustainable Energy Reviews,* Vol. 13, No. 4 (May), 887–894. http://www.sciencedirect.com/science/article/B6VMY-4RRXN26-3/2/939e6082473e246f66594365fafe3f59 (access date November 15, 2010).

RGGI. 2011. RGGI, Inc., home page. http://www.rggi.org/rggi (access date June 27, 2011).

Roets, P. 2009. "Production and Distribution of Sasol Semi-synthetic Jet A-1." ICAO Workshop—Aviation and Alternative Fuels, February 10–12, 2009. http://www.icao.int/WAAF2009/Presentations/31_Roets.pdf (access date July 7, 2011).

Rousseau, R. 2010. *The Future of Woody Biomass in a Renewable Economy.* Mississippi State University Extension Service, Publication 2612. http://msucares.com/pubs/publications/p2612.pdf (access date November 9, 2010).

RSB. 2010. Roundtable On Sustainable Biofuels. http://rsb.epfl.ch/ (access date November 11, 2010).

SAFNW. 2011a. Sustainable Aviation Fuels Northwest home page. http://www.safnw.com/ (access date July 7, 2011).

SAFNW. 2011b. *Powering the Next Generation of Flight.* Sustainable Aviation Fuels Northwest. http://www.safnw.com/wp-content/uploads/2011/06/SAFN_2011Report.pdf (access date July 7, 2011).

SAFUG. 2011. Sustainable Aviation Fuel Users Group home page. http://www.safug.org/ (access date March 3, 2011).

Sagar, A. D. and S. Kartha. 2007. "Bioenergy and Sustainable Development?" *Annual Review of Environment and Resources,* Vol. 32, 131–167. http://merlin.allegheny.edu/employee/M/mmaniate/280/bioenergySD.pdf.

Sasol. 2011. Sasol Takes to the Skies With the World's First Fully Synthetic Jet Fuel. Sasol, Ltd. http://www.sasol.com/sasol_internet/frontend/navigation.jsp;jsessionid=OUUQQANQS1X3XG5N4EZSFEQ?navid=1&rootid=120&articleTypeID=2&articleId=28500003&_requestid=2929581 (access date July 7, 2011).

Shi, A. Z., L. P. Koh, and H. T. W. Tan. 2009. "The Biofuel Potential of Municipal Solid Waste." *GCB Bioenergy,* Vol. 1, No. 5, 317–320. http://graphics8.nytimes.com/images/blogs/greeninc/bio_garbage.pdf (access date November 22, 2010).

Shonnard, D. R., L. Williams, and T. N. Kalnes. 2010. "*Camelina*-derived jet fuel and diesel: Sustainable advanced biofuels." *Environmental Progress & Sustainable Energy,* Vol. 29, No. 3.

Sissine, F. 2007. Energy Independence and Security Act of 2007: A Summary of Major Provisions. Congressional Research Service, Order Code RL34294. http://energy.senate.gov/public/_files/RL342941.pdf (access date November 22, 2010).

Sokhansanj, S. and A. F. Turhollow. 2004. "Biomass Densification—Cubing Operations and Costs for Corn Stover." *Applied Engineering in Agriculture,* Vol. 20, No. 4, 495–499. http://asae.frymulti.com/abstract.asp?aid=16480&t=2 (access date November 22, 2010).

Solena Group. 2010. BA and Solena Plan Waste-to-Biofuel Plant. http://www.solenagroup.com/pdffiles/100726-Farnborough_Press_Notice_July_2010.pdf (access date November 22, 2010).

Stanway, D. 2010. "China to Launch First Aviation Biofuel Flight This Year." Reuters. http://www.reuters.com/article/2010/05/26/china-biofuel-aviation-idUSTOE64P07E20100526?type=marketsNews (access date July 7, 2011).

State of Washington. 2010a. BioDiesel Facility Commercial Environmental Planning Fact Sheet. Governor's Office of Regulatory Assistance. http://www.ora.wa.gov/documents/ENV_008_08.pdf (access date November 5, 2010).

State of Washington. 2010b. *SEPA Guide for Project Applicants.* Department of Ecology. http://www.ecy.wa.gov/programs/sea/sepa/apguide/apguide1.htm (access date November 4, 2010).

Stratton, R. W., H. M. Wong, and J. I. Hileman. 2010. *Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels.* PARTNER Project 28 Report, version 1.2. http://web.mit.edu/aeroastro/partner/projects/project28.html (access date November 1, 2010).

Swenson, D. and L. Eathington. 2006. "Determining the Regional Economic Values of Ethanol Production in Iowa Considering Different Levels of Local Investment." Iowa State University Department of Economics, Grant BIOE2006-01. http://www.econ.iastate.edu/research/webpapers/paper_12687.pdf (access date November 22, 2010).

Taylor, W. 2009. *Survey of Sulfur Levels in Commercial Jet Fuel.* Coordinating Research Council. http://www.crcao.com/reports/recentstudies2009/AV-1-04/CRC%20FinalReportAV-1-04%20-%2002062009.pdf.

Thompson. 2011. Thomson Airways Becomes First Airline to Fly UK Customers on Sustainable Biofuel. Thomson Airways. http://flights.thomson.co.uk/en/249.html (access date October 11, 2011).

U.S. Congress. 2003. Vision 100—Century of Aviation Reauthorization Act. 108th Congress, 1st session. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=108_cong_bills&docid=f:h2115enr.txt.pdf (access date December 20, 2010).

U.S. Congress. 2007. Energy Independence and Security Act. 110th Congress. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_public_laws&docid=f:publ140.110 (access date December 20, 2010).

USDA. 2009. USDA Meets President Obama's 30-Day Biofuels Directive to Help Meet Country's Energy Needs. U.S. Department of Agriculture. http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=2009/06/0201.xml (access date November 11, 2010).

USDA. 2010a. Algae for Biodiesel Production. U.S. Department of Agriculture Cooperative Extension Service. http://www.extension.org/pages/Algae_for_Biofuel_Productioncitations (access date December 20, 2010).

USDA. 2010b. Biomass Crop Assistance Program Fact Sheet. U.S. Department of Agriculture Farm Services Agency. http://www.fsa.usda.gov/Internet/FSA_File/bcapoctrules.pdf (access date October 31, 2010).

USDA. 2010c. Biomass Crop Assistance Program; Final Rule. U.S. Department of Agriculture Commodity Credit Corporation. 7 CFR Part 1450. http://www.fsa.usda.gov/Internet/FSA_File/bcapoctrules.pdf (access date December 21, 2010).

USDA. 2010d. Biorefinery Assistance Guaranteed Loans. U.S. Department of Agriculture Rural Business-Cooperative Service. 7 CFR Parts 4279, 4287 and 4288. http://www.rurdev.usda.gov/rbs/busp/9003%20ProposedRule%2004-16-2010.pdf (access date December 21, 2010).

USDA. 2010e. Business and Cooperative Programs. U.S. Department of Agriculture, Iowa Rural Development. http://www.rurdev.usda.gov/ia/rbs.html (access date November 22, 2010).

USDA. 2010f. Crop and Livestock Insurance. U.S. Department of Agriculture. http://www.apfo.usda.gov/FSA/webapp?area=home&subject=prsu&topic=landing (access date November 11, 2010).

USDA. 2010g. Factsheet on Mustard as a Biodiesel Feedstock. U.S. Department of Agriculture Cooperative Extension Service. http://www.extension.org/pages/Oilseed_Crops_for_Biodiesel_Production#Mustard.

USDA. 2010h. *Growing America's Fuel: An Innovation Approach to Achieving the President's Biofuels Target.* White House Interagency Working Group USDA/DOE. http://www.whitehouse.gov/sites/default/files/rss_viewer/growing_americas_fuels.pdf (access date November 11, 2010).

USDA. 2010i. Introduction to Biodiesel. U.S. Department of Agriculture Cooperative Extension Service. http://www.extension.org/pages/Introduction_to_Biodiesel (access date November 1, 2010).

USDA. 2010j. *Miscanthus* for Biofuel Production. U.S. Department of Agriculture Cooperative Extension Service. http://www.extension.org/pages/Miscanthus_for_Biofuel_Production (access date December 20, 2010).

USDA. 2010k. Price Support. U.S. Department of Agriculture. http://www.apfo.usda.gov/FSA/webapp?area=home&subject=prsu&topic=landing (access date November 11, 2010).

USDA. 2010l. Rapeseed and Canola for Biodiesel Production. U.S. Department of Agriculture Cooperative Extension Service. http://www.extension.org/pages/Rapeseed_and_Canola_for_Biodiesel_Production (access date December 21, 2010).

USDA. 2010m. Rural Business Enterprise Grants (RBEG) Program. U.S. Department of Agriculture. http://www.rurdev.usda.gov/rbs/busp/rbeg.htm (access date November 12, 2010).

USDA. 2010n. Section 9003—Biorefinery Assistance Program, Biorefinery Assistance Loan Guarantees. U.S. Department of Agriculture. http://www.rurdev.usda.gov/rbs/busp/baplg9003.htm (access date December 21, 2010).

USDA. 2010o. Switchgrass for Biofuel Production. U.S. Department of Agriculture Cooperative Extension Service. http://www.extension.org/pages/Switchgrass_for_Biofuel_Production (access date December 20, 2010).

USDA. 2010p. Value-Added Producer Grants (VAPG). U.S. Department of Agriculture. http://www.rurdev.usda.gov/rbs/coops/vadg.htm (access date November 12, 2010).

USDA. 2010q. Waste Oil and Grease for Biodiesel Production. U.S. Department of Agriculture Cooperative Extension Service. http://www.extension.org/pages/Used_and_Waste_Oil_and_Grease_for_Biodiesel (access date December 20, 2010).

USDA. 2011. World Agriculture Supply and Demand Estimates. U.S. Department of Agriculture. http://www.usda.gov/oce/commodity/wasde/latest.pdf (access date December 21, 2010).

Verrengia, J. 2009. Algae-to-Fuel Research Enjoys Resurgence at NREL. http://www.nrel.gov/features/20090403_algae.html (access date November 1, 2010).

Vidal, J. 2010. "One Quarter of U.S. Grain Crops Fed to Cars—Not People, New Figures Show." *The Guardian.* http://www.guardian.co.uk/environment/2010/jan/22/quarter-us-grain-biofuels-food (access date November 11, 2010).

Ward, S. A. D., R. A. Massey, A. E. Feldpausch, Z. Puchacz, C. J. Duerksen, E. Heller, N. P. Miller, R. C. Gardner, G. D. Gosling, S. Sarmiento, and R. W. Lee. 2010. *ACRP Report 27: Enhancing Airport Land Use Compatibility, Volume 1: Land Use Fundamentals and Implementation Resources.* Transportation Research Board of the National Academies, Washington, D.C. http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_027v1.pdf.

Warwick, G. 2009. "Air New Zealand Flight Leads Drive to Biofuels." *Aviation Week.* http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=awst&id=news/aw010509p6.xml (access date July 7, 2011).

The White House. 2011. "President Obama Announces Major Initiative to Spur Biofuels Industry and Enhance America's Energy Security." Press release. http://www.whitehouse.gov/the-press-office/2011/08/16/president-obama-announces-major-initiative-spur-biofuels-industry-and-en (access date October 13, 2011).

Williams, R. B. 2007. "Biofuels from Municipal Wastes—Background Discussion Paper." University of California at Davis, Department of Biological and Agricultural Engineering. http://biomass.ucdavis.edu/materials/reports%20and%20publications/2007/2007_Annual_Forum_Background_Paper.pdf (access date November 22, 2010).

Wiltsee, G. 1998. *Urban Waste Grease Resource Assessment.* U.S. Department of Energy, National Renewable Energy Laboratory, NREL/SR-570-26141. http://www.epa.gov/region9/waste/biodiesel/docs/NREL waste-grease-assessment.pdf (access date December 20, 2010).

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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